SENSITIVITY ANALYSIS OF OPERATIONAL PERFORMANCE UNDER CONVENTIONAL DIAMOND INTERCHANGE AND DIVERGING DIAMOND INTERCHANGE

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SENSITIVITY ANALYSIS OF OPERATIONAL PERFORMANCE UNDER CONVENTIONAL DIAMOND INTERCHANGE AND DIVERGING DIAMOND INTERCHANGE

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To my loving family for being the backbone of my life to keep me going

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LIST OF SYMBOLS AND ABBREVIATIONS

CAP-X	Capacity Analysis for Planning of Junctions
CDI	Conventional Diamond Interchange
CLV	Critical Lane Volume
DDI	Diverging Diamond Interchange
DLT	Displaced Left Turn Intersection
DOT	Department of Transportation
DXI	Double Crossover Interchange
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
LC	Lane Configuration
LUF	Lane utilization factor
MoDOT	Missouri Department of Transportation
MOE	Measure of Effectiveness
mph	Miles per hour
MUT	Median U-Turn Intersection
ParClo	Partial Cloverleaf Interchange
ROW	Right-of-way
SPUI	Single Point Urban Interchange
USC	Upstream Signalized Crossover Intersection
v/c	Volume-to-Capacity
VB	Visual Basic
vph	Vehicle per hour

vphrpln	Vehicle per hour per lane
XDL	Crossover Displaced Left-Turn Intersection

SUMMARY

As the result of changing traffic patterns, many conventional intersections and interchanges can no longer accommodate growing traffic volumes and heavy turning movements. In response, there are various innovative intersection and interchange designs proposed and implemented to better accommodate these changes, and the Diverging Diamond Interchange (DDI) is one of these alternatives. The DDI is designed to better accommodate heavy left-turn movements, and provides simplified signal operations with fewer phases and reduced lost times compared to a Conventional Diamond Interchange (CDI). Previous studies have also found safety and cost benefits of the DDI in comparison to conventional interchange designs.

In contributing to these studies, this effort aims to conduct a sensitivity analysis of CDI and DDI operational performance under various interchange lane configurations, including the selected study area of the Jimmy Carter Boulevard and I-85 interchange in Norcross, Georgia, under varying traffic demands and turn movement ratios. The sensitivity analysis explores the detailed conditions in which one interchange configuration provides superior performance over the other. A literature review is conducted on the DDI background and concepts, benefits and costs of a DDI in comparison to the CDI and other unconventional interchange designs, and methodologies used in previous studies on CDI and DDI operational performance analysis.

The sensitivity analysis is structured into a two-step process. First, a Critical Lane Volume (CLV) method calculates the volume-to-capacity (v/c) ratio of each interchange design using the capacity and volume equations from the Highway Capacity Manual

(HCM) 2010. This allows for a quick analysis of a large number of traffic scenarios. The second part of the analysis is a VISSIM microscopic simulation study. The simulation study is conducted for a subset of the demand scenarios to confirm the comparative performance findings of the CLV analysis. VISSIM allows users to control multiple traffic parameters and allows for more detailed analysis of the network operational performance with various operational measures, such as average delay per vehicles, throughput, queue length and average number of stops per vehicle for individual turning movements as well as for entire interchange.

From the CLV analysis, the CDI is found to perform better or similar to the DDI when the cross street left-turn proportion onto the freeway entrance ramp is below 30% of total cross street demand, and in most cases the DDI outperforms the CDI at left-turn proportion exceeding 50%. The CDIs and DDIs were found to have similar performance in the through/left proportion range of 70/30 and 50/50, often dependent on cross street cross sections. As the number of cross street lanes increases, especially left-turn lanes, the left-turn proportion required for the DDI to provide favorable performance increases. Similar results are found in the VISSIM simulation study based on the average delay per vehicle and average throughput of the CDI and DDI interchange configurations over different through/left proportions. The CDI configuration was also found to have better performance at low cross street demands at given through/left proportion. Although, the CDI operational performance degrades more rapidly than that of the DDI at high cross street demands. The impact of freeway off-ramp demands on the operational performance is inconclusive.

Overall, the study found that a CDI is likely the preferred option at locations with traffic volumes well below capacity and cross street left-turn traffic proportions below 30% of the total cross street demand, and a DDI is likely preferred at locations with traffic volumes near capacity and cross street left-turn proportions exceeding 50% of the total cross street demand. Findings from this study can support planning and decision-making processes associated with the implementation of DDIs.

CHAPTER 1. INTRODUCTION

Rapidly growing traffic demand and changing traffic patterns have led to the operational failure of many segments of the existing transportation infrastructure (Chlewicki, 2003). According to 2015 Urban Mobility Scorecard, national yearly average delay per commuter in 2014 was 42 hours and the total cost of congestion was $160 billion. In the same year, Atlanta, Georgia recorded a yearly delay per commuter of 52 hours, ranked 12th place among large urban areas with population over 3 million, and had a congestion cost of $1,130 per commuter. However, conventional solutions to these problems, e.g. adding more lanes and building more infrastructure, are becoming increasingly difficult to implement. It is getting more difficult to find sufficient funding and right-of-way to expand roadways. As the result, traffic engineers are seeking innovative intersection and interchange designs to better accommodate these challenges. The Diverging Diamond Interchange (DDI) is one such innovative intersection that is receiving increasing interest in the United States.

1.1 Background

The DDI, also called a double crossover diamond (DCD), was first introduced in the United States by Gilbert Chlewicki in 2003. A DDI has crossovers on each side of an interchange to move traffic on left side of the road, opposite to the conventional traffic movement. A DDI eliminates conflicting movements to left-turning vehicles and allows left-turn movements to operate without a dedicated signal phase. Many studies suggested that a DDI improves the operation of turning movements and significantly reduces the number of vehicle-to-vehicle conflict points compared to a conventional diamond interchange (CDI).

Since the first DDI opened at I-44 and MO-13 in Springfield, Missouri on June 21, 2009, 89 DDIs have been built in the United States (as of July 2017) with many more being planned (Chlewicki, 2014). There are five DDIs currently in operation in the state of Georgia.

1.2 Project Goals and Scope

Although previous studies have examined the operational performance of a DDI and compared it to other interchange designs, there not currently guidance or criteria that provide conditions that justify the conversion of a Conventional Diamond Interchange (CDI) into a DDI. Therefore, the primary objective of this study is to evaluate the comparative operational performance of CDI and DDI interchange configurations across a range of traffic demands and turn movement ratios. To achieve this goal, a sensitivity analysis of the operational performance under CDIs and DDIs is conducted for three different lane configurations, including the before-after lane configuration at the selected Jimmy Carter Boulevard and I-85 interchange in Norcross, Georgia.

Independent variables tested in the sensitivity analysis are traffic demand and turn movement ratio, which are two critical variables in the operation of an interchange. These independent variables are tested among different interchange lane configurations to increase the applicability of the findings. The sensitivity analysis is conducted in a two-step process: Critical Lane Volume (CLV) analysis and a VISSIM simulation study. Primary measure of effectiveness (MOE) collected in the study are volume-to-capacity (v/c) ratio and average delay per vehicle, and additional measures of travel time, queue length, and average number of stops per vehicle are collected as well. The scope of the study is limited to the interchange, including off- and on-ramps, bridge segment, and cross streets entering the bridge, and does not include adjacent intersections. This scope limits the number of confounding variables, enhancing the ability to conduct the analysis in a reasonable timeframe and interpret the results.

1.3 Thesis Organization

This thesis is organized in the following manner. CHAPTER 2 presents a literature review on the DDI background and concepts, benefits and costs of a DDI in comparison to a CDI and other unconventional interchange designs, and methodologies used in previous studies on DDI operational performance. CHAPTER 3 presents the methodologies, performance measures, and analysis techniques used in this study. CHAPTER 4 highlights and evaluates results of the sensitivity analysis using the Critical Lane Volume (CLV) method and VISSIM simulation study. Lastly, CHAPTER 5 concludes with a results summary, study limitations, and potential future research.

CHAPTER 2. LITERATURE REVIEW

This literature review aims to provide an overview and background for the DDI layout and operation, analysis, methodology, and published operational performance comparisons with CDIs.

2.1 Diverging Diamond Interchange Design

The DDI is an innovative interchange design first introduced by Gilbert Chlewicki in 2003 at the 2nd Urban Street Symposium in Anaheim, California (Chlewicki, 2003). Figure 1 shows the vehicle movement layout of a DDI. The freeway access and egress are the same for a CDI and a DDI, however, in a DDI, through and left-turn traffic on the cross streets cross to the opposite side (left side) of the roadway between ramp terminals (Bared et al., 2005). In this configuration, the cross street traffic enters the freeway on-ramps uninterrupted, i.e. without a conflict point, eliminating the need for dedicated left-turn phasing from the cross street to the freeway ramp. Thus, a DDI may accommodate heavier left-turn demand than a CDI. As illustrated in Figure 1, a DDI has two traffic signal controlled conflict points, one at each crossover. A two-phased timing plan is implemented at each crossing point with the freeway off-ramp phase simultaneous with the non-conflicting cross street direction of traffic. As the result of the crossovers, through movements in each direction follow a split-phased timing pattern, unlike those in a CDI where through movements typically receive concurrent green indications.

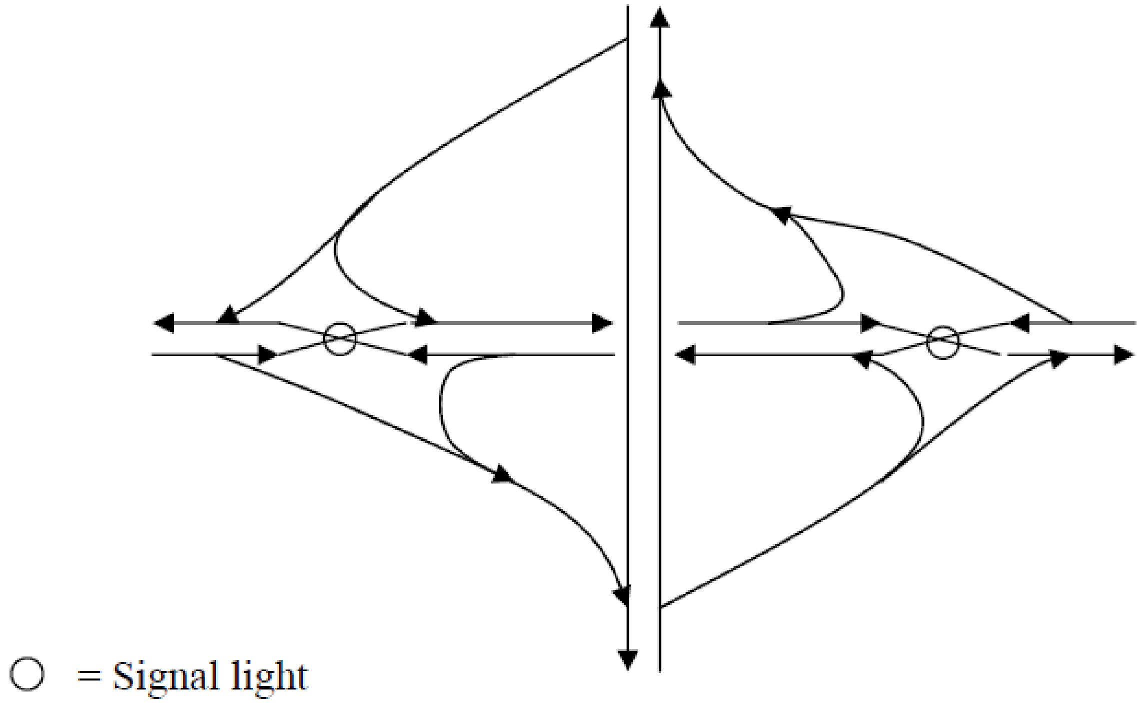


Figure 1: Layout of a diverging diamond interchange (Chlewicki, 2003)

Prior to Chlewicki introducing the concept of the DDI in the United States in 2003, the interchange configuration existed in Versailles, France at Autoroute de Normandie and Boulevard de Jardy (Chlewicki, 2014). The first DDI in the United States opened in June 2009 at the I-44 and SR-13 interchange in Springfield, Missouri. Currently there are 89 DDIs in operation in the United States with the number planned for construction increasing every year (Chlewicki, 2014). DDIs are seeing increasing interest in the United States due to low construction costs and right-of-way (ROW) needs as well as reasonable traffic operations and safety improvements (Chlewicki, 2003; Bared et al., 2005; Edara et al., 2005; Sharma & Chatterjee, 2007; Speth, 2008; MDOT, 2010; Galletebeitia, 2011; Chilukuri, 2011; Chlewicki, 2011; Khan & Anderson, 2016). The following sections will discuss DDI benefits and costs in more detail.

2.2 Diverging Diamond Interchange Costs and Benefits

Various cost/benefit studies have explored DDI performance related to operations, safety, construction costs, etc. The following will summarize several of these studies as well as comparisons to CDIs and other unconventional interchange designs.

2.2.1 Operational Performance of DDI vs. Other Interchange Designs

2.2.1.1 DDI vs. CDI

Chlewicki's first DDI study (2003) compared the original design of the interchange at I-695 and MD 140 in Baltimore County, Maryland to a DDI with the same lane configurations and traffic volumes. Chlewicki found that the total number of stops, total delay, and stop delay at the CDI were two, three, and four-fold respectively, that of the DDI.

Edara et al. (2005) compared DDIs with two different lane configurations (4- and 6-lane) and a CDI (6-lane), for four different traffic scenarios. The study found that similar performance of both DDIs and the CDI design at low-to-medium volume scenarios, but the DDIs outperformed the CDI in all performance measures at high volume scenarios. The DDIs also had a higher maximum off-ramp capacity of 700 vehicle per hour per lane (vphrpln) compared to the CDI with 390 vphrpln. For both DDI lane configurations tested, the capacity of the cross street left-turn to the freeway on-ramp was twice that of the CDI, a benefit of the left-movement being uninterrupted, i.e., moving throughout the cycle.

Other studies conducted by Bared et al. (2005), Sharma & Chatterjee (2007) and Speth (2008) concluded that DDIs outperformed CDIs in most tested traffic scenarios, and the difference in performance was larger at high flow levels and heavy left-turn movements. All studies showed that DDIs operated better than CDIs despite fewer lanes on the bridge segment. Bared et al. (2005) also found that capacities of all signalized movements were higher for the DDI and that the DDI cross street to on-ramp left-turn movement capacity was twice that of the CDI.

Chilukuri et al. (2011) conducted a before-and-after analysis of the DDI at I-44 and Route 13 in Springfield, Missouri and concluded that overall traffic flow through the DDI improved relative to the previous CDI. Despite the increase in traffic volumes after DDI implementation, the DDI had significantly lower delay and queuing for left-turn movements than the CDI. The DDI had a slight increase in the through-movement travel time due to slower speeds through the crossover intersections during off-peak periods. Chilukuri et al. also highlighted that over-dimension loads up to 18ft wide and 200ft long successfully moved through the DDI.

In addition to higher left-turn movement capacity, DDI's operational benefits also come from its ability to combine phases that conflict in the CDI configuration. For instance, freeway on- and off-ramp phases can be combined with mainline through movements. Also, the reduction of a phase compare to a CDI reduces lost time in a cycle, and thus, reduces delay (Chlewicki, 2003). Similar findings were seem in a Missouri DOT (MoDOT)'s report based on MoDOT's experience with DDIs (2010). MoDOT found that signal operations were improved by converting from a CDI to a DDI, having fewer phases, a shorter cycle length, and lower lost time.

However, a DDI is not the solution for all traffic conditions. Khan & Anderson (2016) evaluated DDIs as possible solution for existing interchanges in Athens, Alabama by testing 83 traffic scenarios. The results show that only four scenarios had lower delay for the DDI, likely due to relatively low turning movements relative to the through movements. Chlewicki (2011) suggested that while DDI is not always the best option, there is sufficient evidence to suggest that a DDI should always be considered in an interchange improvement analysis. The results from the experiment with 15,626 volume combinations show that the DDI has superior operations than the CDI when costs are similar, and the DDI is the better option if an interchange requires more lanes to accommodate higher traffic volumes.

2.2.1.2 Comparison with Other Interchange Design Alternatives

Additional studies have explored DDI performance in comparison to other unconventional interchange design alternatives. Speth (2008) was one of the first to compare the operational performance of a DDI to a Single Point Urban Interchange (SPUI). The study found that the SPUI performs slightly better than the DDI at low volume scenarios, but the DDI outperforms the SPUI in all other scenarios in vehicle throughput, average delay per vehicle, and average number of stops per vehicle, with fewer lanes in the bridge section.

Galletebeitia (2011) conducted a study to compare and evaluate the operational performance between a DDI and Partial Cloverleaf (ParClo) interchanges using the microscopic simulation platform, AIMSUN. 16% of all US interchanges are a ParClo configuration. ParClo interchanges are often selected for their accommodation of heavy left-turn movements, similar to a DDI. There are several ParClo interchange configurations, categorized as ParClo A (indicating a cloverleaf configuration on an on-ramp), ParClo B (cloverleaf configuration on an off-ramp), and ParClo AB (cloverleaf configuration on both on- and off-ramp). In addition, a ParClo configuration may utilize from one to four quadrants interchange. Figure 2 shows six types of ParClo interchange (Zhang et al., 2010). Zhang et al. conducted a study focused on evaluating ParClo A4 and ParClo B4 interchanges, and 4-lane and 6-lane DDIs (DDI-4, DDI-6). The study tested 10 volume scenarios in balanced and unbalanced conditions. The study found that the DDI and ParClo interchange performance are similarly at low-to-medium volumes in both balanced and unbalanced conditions. In the balanced condition, ParClo interchanges experienced lower delays, stop times and number of stops compared to the DDIs, although the difference in delay between DDI-6 and ParClo B4 decreased as the traffic flow increased. The ParClo B4 resulted in the longest maximum queue as the flow increased. In the unbalanced condition, ParClo B4 showed the best results in all measures at low-to-medium volumes, but both DDI-4 and DDI-6 resulted better performance than the ParClo interchanges as the flow increased. The study concluded that ParClo interchanges perform better in balanced conditions with low-to-medium traffic flow, and DDIs perform better in unbalanced conditions at high flow.

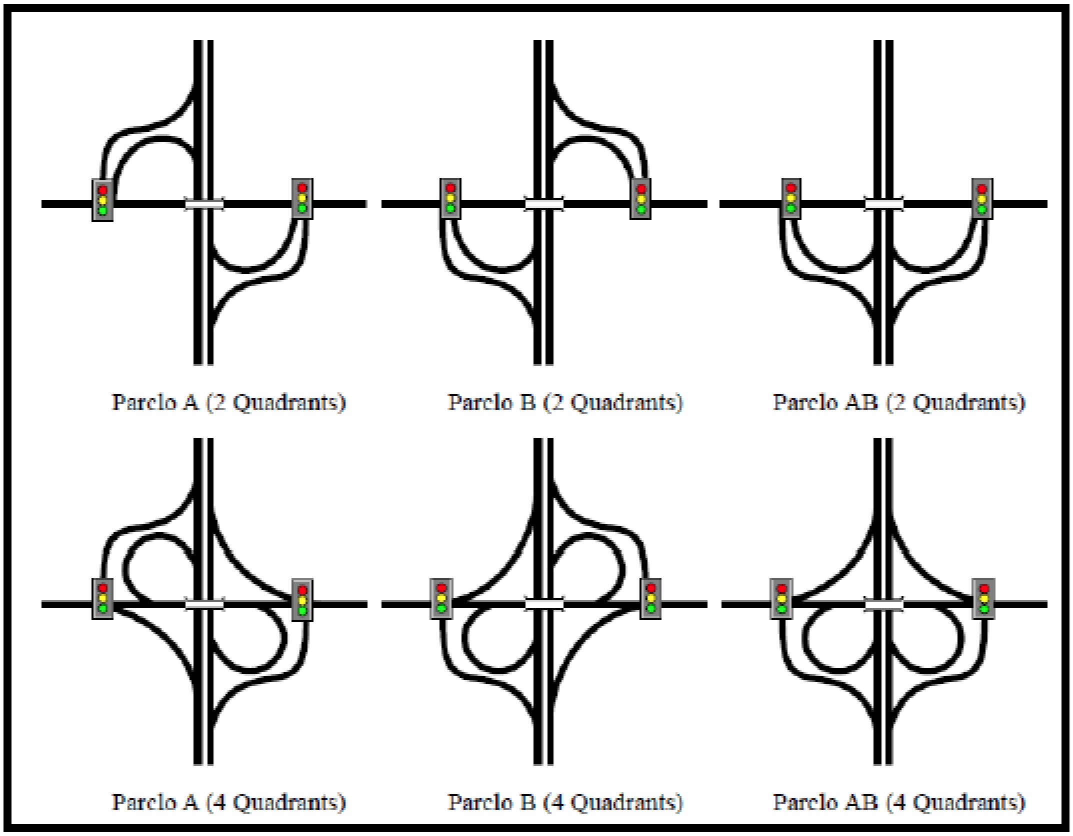


Figure 2: Six types of Partial Cloverleaf (Zhang et al., 2010)

Autey et al. (2012) conducted a study to compare the operational performance of four unconventional intersection designs: crossover displaced left-turn (XDL), upstream signalized crossover (USC), diverging diamond intersection (DDI), and median U-turn (MUT), as well as a CDI with equal lane configurations in balanced and unbalanced volume conditions. The results show that all tested unconventional designs perform better than the CDI in most cases, and the improvements become more significant at high traffic volumes. Among the tested unconventional designs, the XDL consistently outperformed other designs under both balanced and unbalanced volume conditions, especially at high volumes. In balanced traffic volumes, XDL, USC, and DDI performed equally well for moderate approach volumes (1100-1500 veh/hr), but for the approach volume higher than 1500 veh/hr, the XDL outperformed other intersections. In unbalanced conditions, the

XDL always outperformed other intersection designs in all volume scenarios. The DDI performed better than the USC in most unbalanced conditions (ratio between the minor and the major street volumes less than 70%). The MUT resulted the highest average delay per vehicle, especially with high approach volumes and heavy left-turning ratios. However, the XDL and the MUT require greater right-of-way to accommodate their designs, and hence, may not be appropriate alternatives to a CDI in many cases.

2.2.2 Other Benefits and Costs

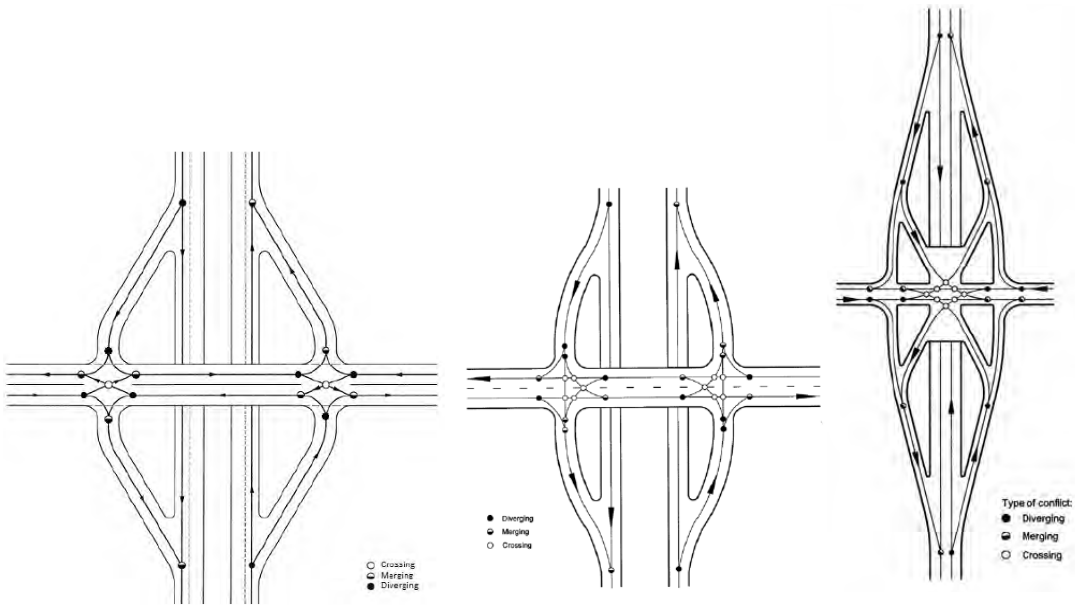
Numerous studies suggest that DDIs have several safety benefits over other interchange designs. Its unique design eliminates left-turn movement conflicts. With 24 and 30 conflict points respectively, both the SPUI and the CDI have more conflict points than a DDI (Chlewicki, 2003; Cogan, 2008; MoDOT, 2010; Ressel, 2012). Figure 3 shows the conflict diagrams of a CDI, a DDI and a SPUI.

A DDI also provides for easier U-turn movements on a limited access highway, allowing a vehicle to return to a missed exit (MoDOT, 2010). In a CDI, drivers must go through two signalized left-turns to re-enter the highway, whereas, for a DDI a returning vehicle must past through only one signal as the on-ramp left-turn is uninterrupted. A DDI also eliminates wrong-way movements to and from ramps. However, in the DDI interchange configuration the intersection crossover prohibits a vehicle's through movement from an off-ramp to an on-ramp to re-enter the highway.

A concern related to the DDI configuration is the potential for confusion given the unfamiliarity of drivers with the crossover intersections and driving on the left side of the road. However, this disadvantage can be mitigated through an aggressive public information campaign and appropriate education by states and cities (Chlewicki, 2003; MoDOT, 2010). According to an online and phone survey conducted by Chilukuri (2011) on the DDI at I-44 and Route 13, 91% of participants expressed a good understanding of the operation of the DDI and more than 80% stated that the traffic flow had improved and delay had decreased with the DDI conversion. Several studies argued against the crossover intersection concern stating that the driver unfamiliarity has a calming effect by encouraging slower speeds while approaching and crossing the interchange, thus serving as a potential safety benefit (MoDOT, 2010; Ressel, 2012). According to the MoDOT survey, 97% of drivers said they feel safer in the DDI than the previous CDI. A five month comparison of crash data for the DDI in Springfield, Missouri shows 60% reduction over the previous diamond interchange (MoDOT, 2010). The crash data review by Chilukuri (2011) also shows 46% decrease in total crashes in the first year of opening of the DDI, elimination of left-turn crashes, and a decrease in angle and rear-end crashes.

A DDI is also known to have lower a construction cost compared to other interchange alternatives. In many cases, an existing bridge can be used for the DDI conversion. Although a DDI may require additional right-of-way compare to a CDI to allow median and ramp terminals to bend into the road. However, Hughes et al. (2010) found that a four-lane DDI performs at a similar level as a six-lane CDI, and a six-lane DDI performs similar to an eight-lane CDI. This reduction in lanes indicates that a DDI in many cases may provide a similar or better level of operation with little or no additional right-of-way from the existing CDI. A DDI also requires less right-of-way than a SPUI or displaced left-turn intersection (DLT), and similar right-of-way but higher capacity than ParClo interchange (Chlewicki, 2003; Chlewicki, 2011; Stanek, 2008; Hughes et al., 2010;

Ressel, 2012). The comparison of construction costs among DDIs in four locations in the United States and alternative designs is shown in Appendix A, which shows that there are up to 75% cost savings from constructing DDIs over other alternatives (Chlewicki, 2014).



(a) (b) (c)

Figure 3: Conflict diagram of a) DDI b) CDI c) SPUI (MoDOT, 2010)

2.3 Methodologies in Diverging Diamond Interchange Studies

The studies discussed in the previous sections used several different methodologies to evaluate and compare the operational performance of DDIs and other interchange designs. Three major methodologies are reviewed: microscopic simulation, critical lane volume (CLV) method, and travel-time measurement using video recording.

2.3.1 Microscopic Simulation Study

Microscopic simulation is the most popular tool used in DDI studies. While Chlewicki (2003) used Synchro (an analytic tool) to analyze the operational performance of a CDI and a DDI in his first DDI paper, many other studies have since relied on microscopic simulation, including VISSIM, AIMSUN, Corsim, and Synchro with SimTraffic, to measure and compare the performance of DDIs and CDIs. These include Bared et al (2005), Edara et al. (2005), Schroeder et al. (2006), Sharma & Chatterjee (2007), Speth (2008), Chlewicki (2011), Chilukuri et al. (2011), Galletebeitia (2011), Ressel (2012), Yeom et al. (2014) and Khan & Anderson (2016). Microscopic simulation software has the capability to analyze the operational performance of an interchange at various traffic conditions with varying traffic volumes and turn movement ratios, a range of vehicle types, and alternative geometric configurations. Xiao et al. (2005) and Schroeder et al. (2006) concluded in their papers that microscopic simulation tools are capable of replicating observed vehicle behaviors and meeting most of the standard traffic modeling requirements with careful calibration and validation.

The use of VISSIM is widespread among interchange operational performance studies. VISSIM is a microscopic simulation program that has the capability to replicate driver behavior, geometry, and traffic controls accurately for various roadway designs (Ressel, 2012). What distinguishes VISSIM from other microscopic simulation tools is the ability to calibrate the driver behavior modeling. Other popular tools, such as Synchro with SimTraffic, have deterministic arrival patterns, lane change behaviors and look back distances. All of these parameters can be controlled in VISSIM, which adds reliability and accuracy to the model and its outcomes (Ressel, 2012).

According to Schroeder et al. (2006) and Woody (2006), calibration and field validation are essential to developing accurate VISSIM models. Schroeder et al. (2006) stated that important VISSIM model calibration factors include origin-destination volumes, route decision look-back distances, field-measured free-flow speeds, and field-implemented signal timing schemes. Validation parameters include travel time through the network and each route, as well as average, 95^{th}, and maximum queue lengths on a per cycle basis. Woody (2006) provided a guideline for the calibration of VISSIM models and suggested the importance of the car following behaviors, lane changing behavior, and standstill distance for operational calibration and study area size, analysis period, volume, route choice, traffic control, network speed and roadway geometry for system calibration.

2.3.2 Critical Lane Volume Method

A limitation of a microscopic simulation study is that it can be costly and time-consuming depending on the length and the number of simulation inputs, and thus, only a limited number of traffic scenarios may be analyzed. As an alternative, Chlewicki (2011) and Maji et al. (2013) used the Critical Lane Volume (CLV) method. CLV uses mathematical equations from Highway Capacity Manual (HCM) to calculate the capacity per lane of critical movements and then compares these capacities to the demand and estimates a level-of-service for the DDI. The CLV method is straightforward and less time-consuming than microscopic simulation, allowing for the analysis of a large number of alternatives in relatively short time with reasonable reliability.

Using the CLV method, Chlewicki (2011) analyzed 15,626 volume combinations to compare the operation of a DDI and a CDI. Maji et al. (2013) found that the CLV method could provide reliable and accurate outcomes for DDI operational performance in comparison to VISSIM and Synchro. The Federal Highway Administration (FHWA) introduced the Capital Analysis for Planning of Junctions (CAP-X) in the Diverging

Diamond Interchange Information Guide (2014) as a principal planning-level tool to analyze and compare the operational performance of several interchange designs, including a DDI, using the CLV method. CAP-X uses inputs of turning movement counts, heavy vehicle percentages, and number of lanes on each approach to estimate v/c ratios at each crossing points of different junction designs.

However, Chlewicki (2011) pointed out several limitations of the CLV method. First, the CLV method is only capable of analyzing individual intersections, but cannot determine how signals or intersections will synchronize, an issue for interchanges as they typically have two or more intersections. Second, the CLV method is likely to ignore issues associated with a CDI, and thus, overestimate CDI performance relative to other alternatives. For instance, A CLV analysis may assume the same capacity of all interchange intersections regardless of interchange form. However, a DDI crossover intersection likely has a higher per-lane capacity than a CDI intersection as the DDI has one less phase, and thus less lost time per hour. Chlewicki also pointed out that the CLV method requires careful selection of lane adjustment factors for accurate results. Maji et al. (2013) concluded that it is better to use microscopic simulation tools for detailed operational performances analysis of interchanges as the CLV method utilizes limited parameters. For instance, CAP-X does not use phase timings or saturation flow to calculate the capacity, instead requiring users to input the junction capacity. Also, by considering intersections in isolation CAP-X does not capture the reduction in demand on a downstream approach as the result of upstream operational failure.

2.3.3 Other Methodologies

In addition to the microscopic simulation and the CLV method, Chilukuri (2011) conducted travel time runs, video recording, peak hour traffic volume data, crash data review and online surveys to measure DDI operation performances. These methodologies were utilized in part to check the accuracy and reliability of the simulation results.

2.3.4 Traffic Scenario Selection Methodologies

Although many studies used similar tools for the analysis, there are differences in how they developed volume and route decision scenarios to test the operational performance of DDIs and CDIs.

2.3.4.1 Existing Volumes vs. Hypothetical Volumes

The operational performance of a DDI and a CDI can be analyzed using either existing volume data from the study area or hypothetical volumes developed by researchers. For example, Chlewicki (2003) evaluated CDI and DDI operational performance using the existing traffic volumes and turning movement distributions for the interchange at I-695 and MD 140 in Baltimore County, Maryland. Chilukuri (2011), Ressel (2012) and Maji et al. (2013) also used existing volume data for their study interchanges and projected 2035 traffic volumes based on the existing data to evaluate DDI performance. Schroeder et al. (2006) also used existing traffic volumes of four DDIs in Tennessee and Missouri to present an approach for calibrating and validating DDI models using VISSIM. Khan & Anderson (2016) developed 83 volume scenarios based on the existing volumes at a CDI in Athens, Alabama with volume increases of 0%, 50%, 100%, 150% and 200% of existing.

Bared et al. (2005), Edara et al. (2005), Sharma & Chatterjee (2007), Speth (2008), Galletebeitia (2011), and Autey et al. (2012) used hypothetical combinations of volumes and turning movements to test the operational performance of interchanges. Chlewicki (2011) tested 15,626 volume combinations based on the permutation of five left-turn and through movements. Bared et al. (2005), Sharma & Chatterjee (2007) and Galletebeitia (2011) categorized the traffic volumes in peak, high, medium, and low flow rates.

2.3.4.2 Balanced and Unbalanced Traffic Volume

Another variable in traffic scenario selection is balanced and unbalanced traffic. Balanced traffic refers to opposing approaches (e. g. east- and westbound or north- and southbound) having equal traffic volumes and/or turning movement distributions. Unbalanced traffic refers to opposing approaches having different traffic volumes and/or turning movement distributions. Examples of balanced and unbalanced volume conditions are illustrated in Table 1. Chlewicki (2003), Bared et al. (2005), Edara et al (2005) and Chilukuri et al. (2011) studied the operational performance of DDIs under balanced volume conditions only. Ressel (2012) and Maji et al. (2013) tested DDIs under unbalanced conditions only. Sharma & Chatterjee (2007), Speth (2008), Chlewicki (2011), Galletebeitia (2011), Autey et al. (2012) and Khan & Anderson (2016) analyzed the operations of DDIs and CDIs under both balanced and unbalanced traffic volumes. Chlewicki (2011) and Autey et al. (2012) also analyzed DDIs at different left-turn ratios to evaluate the impact of left-turn proportions on the operation of DDIs.

Table 1: Balanced and unbalanced volumes (Speth, 2008)

	Northbound		Southbound		Eastbound			Westbound		
	L	R	L	R	L	T	R	L	T	R
Balance	200	200	200	200	700	500	100	700	500	100
Unbalance	500	200	260	70	160	400	700	330	470	300

* L: Left-turn, R: Right-turn, T: Through

CHAPTER 3. METHODOLOGY

The DDI and CDI sensitivity analysis in this study is based on the operational performance studies discussed in the literature review. The following sections describe in detail the analysis methodology, including lane configuration and traffic scenario selection, network designs, and sensitivity analysis steps and inputs.

3.1 Overview Flow Chart of the Study Procedure

The following flow chart (Figure 4) provides an overview of the step-by-step procedure of the analysis conducted in this study. Detail descriptions of each step in the flow chart are provided in the following sections of this chapter. As will be seen, the study starts with a selection of CDI and DDI configurations along with a range of demand scenarios. For each configuration and demand scenario, optimal signal timing plans are determined using the optimization tool Synchro. A CLV analysis is then conducted for each configuration and demand scenario, allowing for a comparison of DDI and CDI performance under a wide variety of conditions. A more in-depth analysis of a subset of the scenarios is then undertaken using the VISSIM microscopic simulation tool. The CLV and VISSIM findings are then summarized to help inform the selection of a DDI or a CDI configuration in the design planning stage of a project.

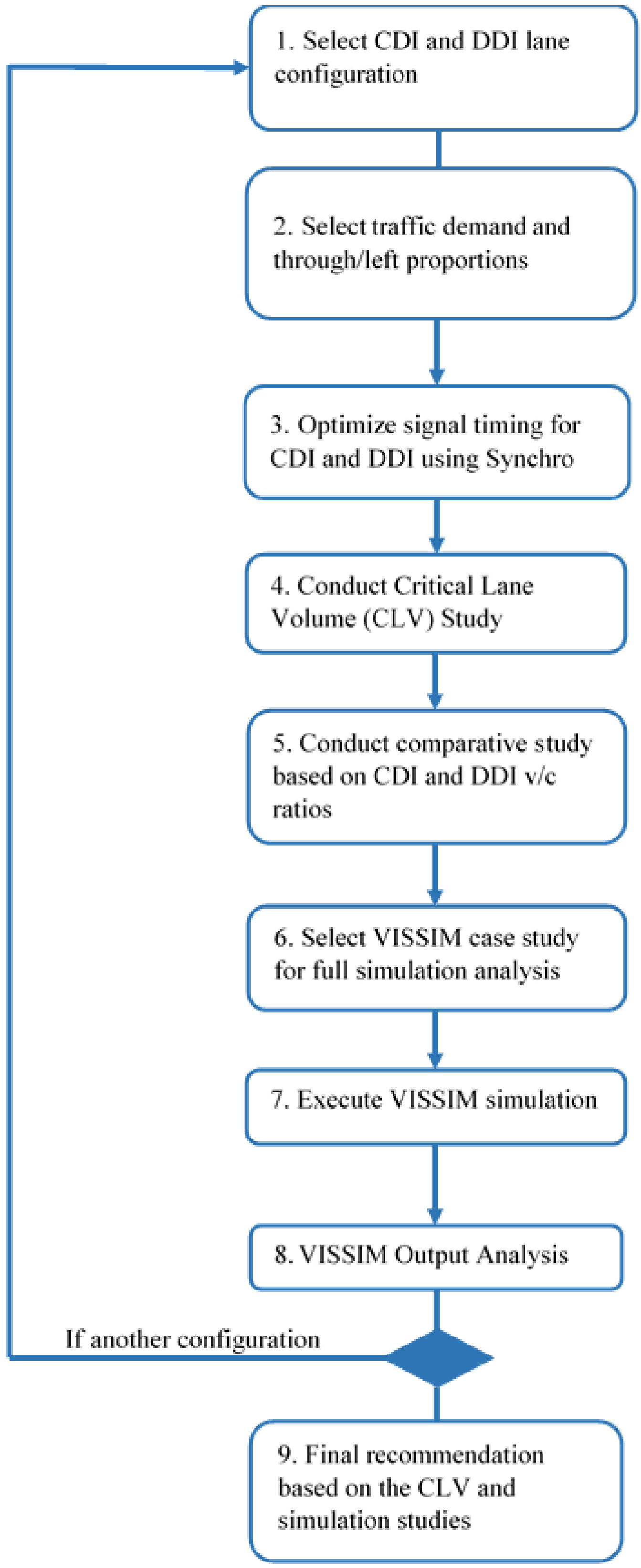


Figure 4: Flow Chart of the Study Procedure

3.2 Lane Configuration Selection

The first step in the analysis is to select interchange lane configurations to be tested. Analysis of various lane configurations allows for a broad application of the study findings.

The initial CDI and DDI configurations in this study were based on the before and after interchange designs at Jimmy Carter Boulevard and I-85 in Norcross, Georgia. Figure 5 and Figure 6 show the aerial pictures of before-and-after configurations of the selected site. This interchange was converted to a DDI in 2015 in response to severe traffic congestion. For this report the cross street, Jimmy Carter Boulevard, is designated as north-south and the freeway, I-85, as east-west. Before the conversion, the northbound interchange approach had four through lanes with a right-turn-only lane and the southbound approach had three through lanes with a right-turn-only lane. On the bridge, there were two through lanes and two left-turn lanes northbound, and two through lanes and one left-turn lane southbound. Both I-85 off-ramps (eastbound and westbound) to Jimmy Carter Boulevard had two left-turn lanes and one right-turn lane. After the DDI conversion, the interchange has three through lanes and one right-turn lane on both the northbound and southbound approaches, and one through-only lane, one through plus left shared lane, and one left-turn-only lane northbound and southbound on the bridge. The after off-ramp lane configurations are the same as in the before configuration. The before and after lane configurations are indicated as LC1 (Lane-Configuration-1) in subsequent analysis.

Two other CDI vs. DDI lane configurations were also modeled: a) three entering lanes on cross street with two through lanes and one left-turn lane on the bridge in northbound and southbound directions (indicated as LC2); and b) four entering lanes on cross streets, two through lanes and two dedicated left-turn lanes on the bridge in the northbound and southbound directions (indicated as LC3). The off- and on-ramps remain the same for all configurations. Unlike the first lane configuration tested, the other two lane configurations have an equal number of lanes on both CDI and DDI southbound and northbound approaches.

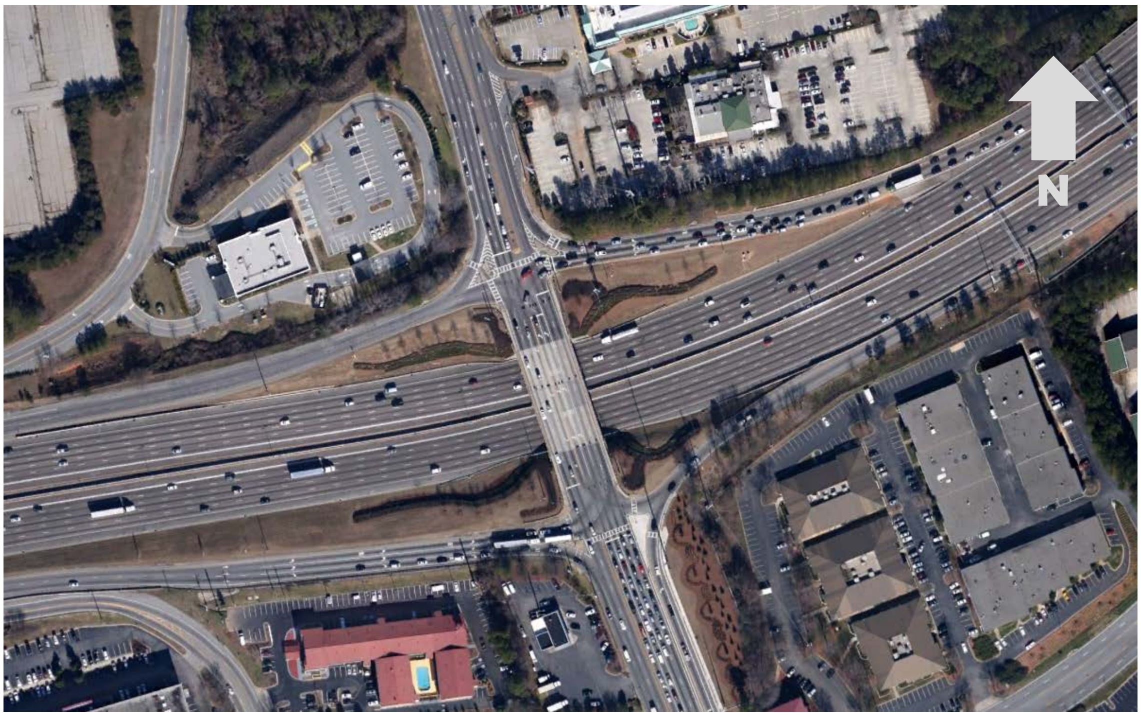


Figure 5: Before configuration of the Conventional Diamond Interchange at Jimmy Carter Boulevard and I-85 in Norcross, GA (Google Earth®, accessed 11/28/2017)

Figure 6: After configuration of the Diverging Diamond Interchange at Jimmy Carter Boulevard and I-85 in Norcross, GA (Google Earth®, accessed 11/28/2017)

3.3 Sensitivity Analysis of DDI and CDI

Sensitivity analysis is "a technique used to determine how different values of an independent variable impact a particular dependent variable under a given set of assumptions." (Investopedia, 2017) In this study, independent variables examined in the analysis are traffic demand, defined by number of vehicles per hour entering the network, and turn movement ratio, defined by the proportion between through and left-turn movements of vehicles coming into the interchange from the cross street of Jimmy Carter Boulevard. The following sections describe in detail the steps and parameter settings selected to perform the DDI and CDI operational performance sensitivity analysis.

3.3.1 Sensitivity Analysis Structure and Assumptions

The sensitivity analysis in this study is structured in two-step process: a CLV analysis and a microscopic simulation study. The CLV analysis calculates and compares volume-to-capacity (v/c) ratios of the DDIs and CDIs for all the traffic scenarios under consideration. The CLV analysis allows for a relatively quick comparison of DDI and CDI operational performance across a large number of demand scenarios. A VISSIM simulation (a common microscopic simulation tool, see section 2.3.1) study is then conducted to confirm the comparative performance findings of the CLV analysis. Microscopic simulation allows a researcher to control various traffic elements including vehicle volume, speed, car-following model, route decision, vehicle composition, and lane change behavior. It also allows for a more detailed analysis of interchange operations compared to the CLV analysis through various operational measures, such as travel time, delay, number of stops, throughput, and queue length. As stated in CHAPTER 2, the drawback of microscopic simulation is that it is much more time-consuming and labor intensive than CLV, thus the VISSIM analysis focuses on a subset of the demand scenarios.

3.3.2 Traffic Scenarios Selection

Traffic scenarios consist of hourly traffic demand and turn movement ratios. As the objective of this study is to compare interchange configurations under various demand scenarios, a large number of volume-proportion combinations are needed. Table 2 and Table 3 below list all volumes and turn movement ratios tested in this study. Each demand scenario is tested for all through/left proportions listed. These volume and turn movement ratios result in 210 different traffic scenarios. In this study, only balanced volume conditions were tested where northbound-southbound and eastbound-westbound approaches have equal volumes and turn movement ratios.

Table 2: Vehicle volumes tested in the study

Cross street Volume (vph)	Off-Ramp Volume (vph)			
	Low	Medium	High	High-2
1000	200	500	800	
1500	500	1100	1800	
1800	500	1100	1800	
2100	500	1100	1800	
2300	500	1100	1800	2100
2500	500	1100	1800	2100
2700	500	1100	1800	

Table 3: Turn movement ratios tested in the study

Through/Left Proportions	
Through	Left
1	0
0.9	0.1
0.7	0.3
0.5	0.5
0.3	0.7
0.1	0.9
0	1

Several assumptions are included in the demand scenarios. First, vehicles exiting the freeway do not return to the freeway, that is, no vehicle from an off-ramp uses the on-ramp back to the interstate. This implies that all vehicles entering the bridge from an off-ramp make a through movement at the exiting crossover intersection. Second, the Through/Left proportion applies only to vehicles that enter the bridge from the cross street; vehicles from the off-ramp are not considered in the through-left volume proportion calculation. For example, the through/left proportion of 70/30 indicates 70% of vehicles entering the bridge from the cross street make a through movement at the exiting crossover intersection while the remaining 30% turn left onto the freeway on-ramp. Third, the freeway off-ramp vehicles are evenly split between left and right turns at the cross street intersection. Finally, 20% of the arriving cross street vehicles turn right to the freeway on-ramps, indicating 80% of vehicles entering the bridge.

3.3.3 Synchro Signal Optimization

As part of the sensitivity analysis optimal signal timing plans for each lane configuration and traffic demand scenarios were determined. For this effort Synchro is used to optimize the both the CDI and DDI signal timing plans.

Synchro models of the DDIs and CDIs were developed based on Jimmy Carter Boulevard and I-85 aerial maps from Bing. Synchro models for both interchange configurations include the off- and on-ramps, bridge segment, and cross streets entering the bridge. The models excluded the adjacent intersections from the analysis to simplify the signal optimization.

DDI models were optimized with pretimed setting and CDI models were optimized with actuated-coordinated setting with loop detectors on left-turn lanes. Cycle lengths of both interchange designs were optimized within the range of 50 seconds and 180 seconds, and the offset was referenced to beginning of green of the northbound through (NBT) phase. These decisions were based on the existing signal implementations at the selected site provided by Gwinnett County DOT.

The basic dual ring diagrams of the DDI and CDI models were developed based on the existing timing plans from Gwinnet County DOT. Sample dual ring diagrams of the

DDI and the CDI are shown in Figure 7 and Figure 8. The DDI has a split-phase configuration of the cross street through movements, with no phase for the left-turn movements from the cross street to the on-ramps, as these are uninterrupted movements in the DDI configuration. The CDI has protected left-turn movements from the cross street to the freeway on-ramp at both bridge intersections. Based on these phase diagrams, the DDIs are expected to benefit from free-flow left-turn movements and reduced lost time per cycle, although the DDI may have reduced cross street capacity given the through movement split-phase timing configuration.

From the signal timing optimization using Synchro, the phase lengths, cycle lengths, and offsets on each intersection are collected.

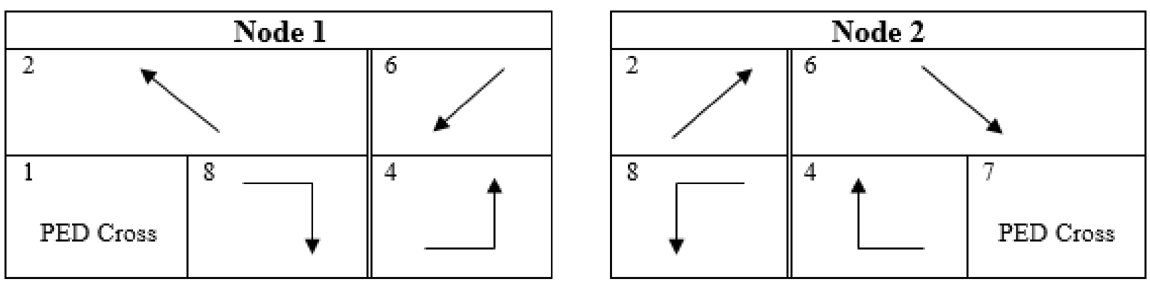


Figure 7: Sample dual ring diagram of the Diverging Diamond Interchange

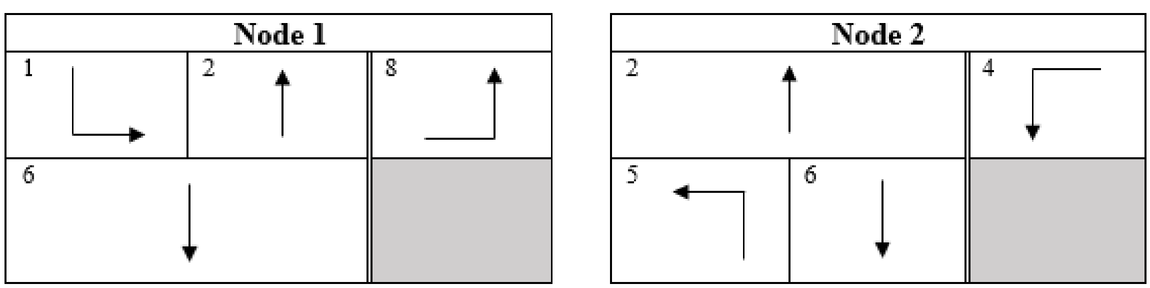


Figure 8: Sample dual ring diagram of the Conventional Diamond Interchange

3.3.4 *Critical Lane Volume Analysis*

The first part of the sensitivity analysis is the CLV analysis comparing DDI and CDI critical movement v/c ratios. A critical movement (or movement pair) is defined as the movement(s) with the highest per lane demand (v/c) on each side of the ring barrier. The critical path consists of the critical movements from both sides of the dual ring diagram. Movements considered in the CLV analysis of the CDI and the DDI defined in this study are listed in Table 4. Figure 9 and Figure 10 illustrate the turning movement schematics of the CDI and the DDI. As seen, for the CLV analysis the movements EBR1, NBR1, SBR2, and WBR2 are not considered as they are uninterrupted movements and unlikely to be capacity constrained. SBL1 and NBL2 are considered in the analysis as these are phase controlled in the CDI configuration and may be capacity constrained; however, in the DDI these movements are uninterrupted.

Table 4: DDI and CDI Critical Movements

Intersections	DDI	CDI
Node 1	NBT1	NBT1
	SBT1	SBT1
	SBL1	SBL1
	EBL1	EBL1
Node 2	NBT2	NBT2
	NBL2	NBL2
	SBT2	SBT2
	WBL2	WBL2

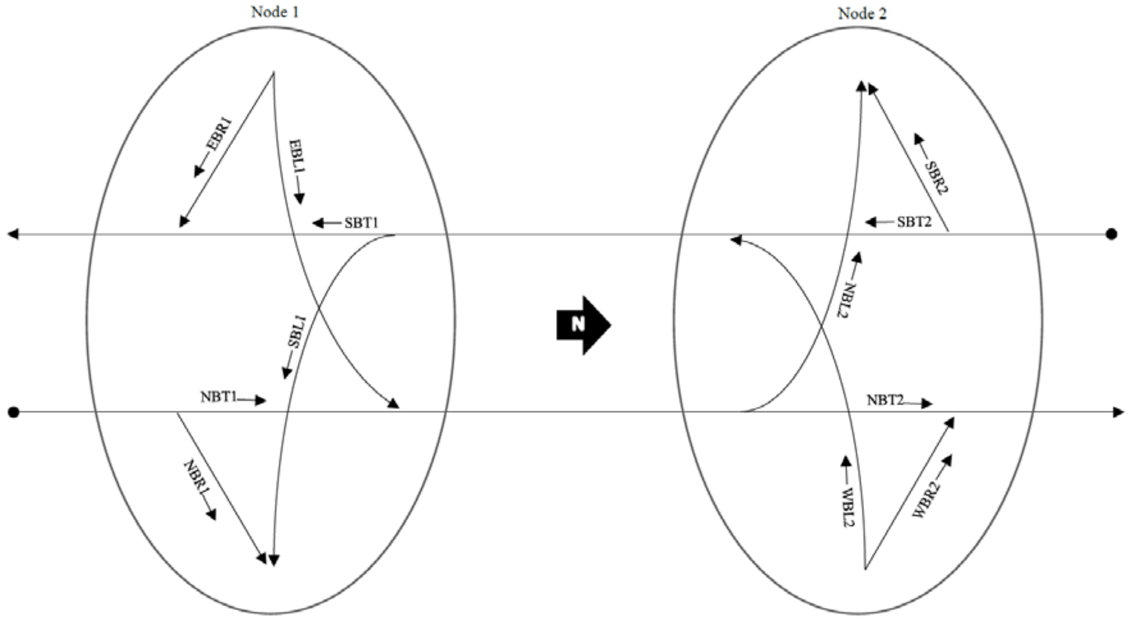


Figure 9: Turning movement schematic of the Conventional Diamond Interchange

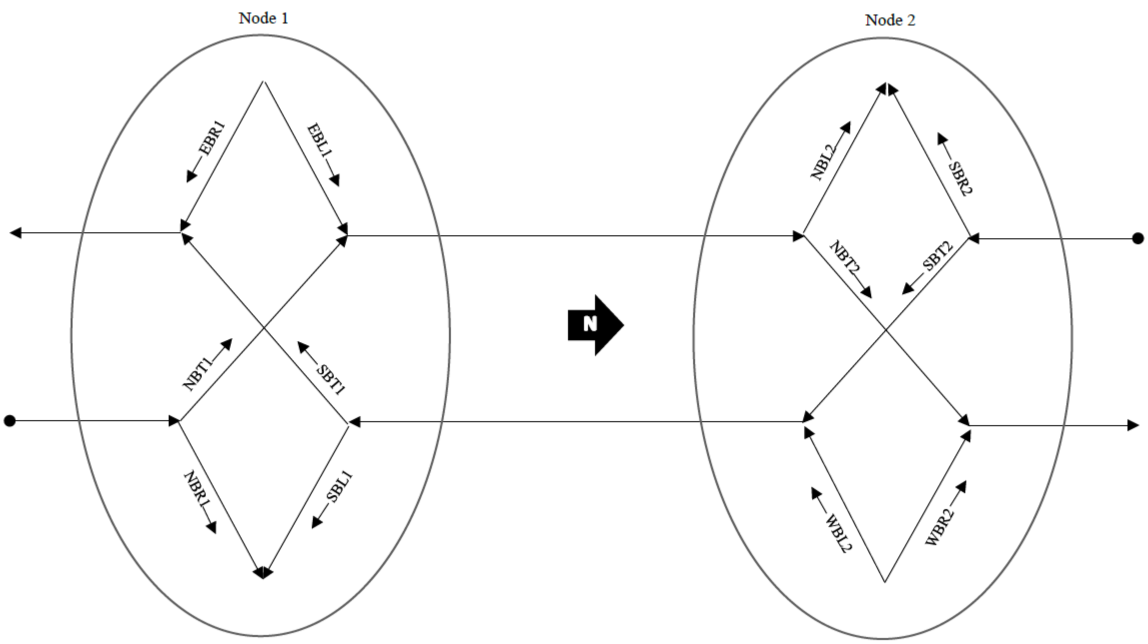


Figure 10: Turning movement schematic of the Diverging Diamond Interchange

3.3.4.1 Volume-to-Capacity Calculations

CAP-X from FHWA is not used in this study for v/c ratio calculation as capacity must be manually set. In addition, CAP-X does not capture the reduction in demand on a downstream approach resulting from an upstream capacity constraint. Instead, v/c ratios of CDIs and DDIs are calculated using simplified HCM 2010 methods. Equation 1 below calculates the capacity per lane for each turning movement within the interchange. Phase lengths and cycle lengths used in the CLV analysis are from Synchro signal optimization. As the CLV analysis is a planning level analysis, and thus intended as an approximation, saturation flow is set to be 2000 vphrpln based on VISSIM results. In addition, a 4 second lost time per phase is assumed. However, in a future iteration of the CLV analysis these values could be adjusted to reflect specific field conditions for increasingly fine-tuned results.

$$\mathrm{c} = \mathrm{s} \times \frac{g}{C} \tag{1}$$

c = capacity per lane (vphrpln)

s = saturation flow, assumed as 2000 vphrpln

g = effective green time, calculated as phase time minus lost time of 4 seconds

C = cycle length of the intersection in seconds

Equation 2 calculates the demand per lane for each movement using the assigned (i.e. scenario) traffic flows and lane utilization factors.

$$v = q \times LUF \tag{2}$$

v = volume per lane (vphrpln)

q = assigned movement traffic flow on each movement (vph)

LUF = lane utilization factor

Table 5 shows the calculation for the LUF for the various lane groupings. The LUF factors are developed with consideration of lane assignments (left only, through only, or shared left-through), the number of lanes, and the relationship between upstream and downstream intersections. LUFs are assumed to maximum lane utilization (i.e., distribution of vehicles across lanes) with the exception that weaving on the bridge is minimized. That is, a vehicle will not preposition in an upstream lane that does not lead to a downstream lane allowing that movement (exclusive or shared). These assumptions tend to lead to a conservation allocation of vehicles, particularly on a DDI with a shared through-left lane, likely underutilizing the left turn only free flow lane. However, as this is a planning level analysis the more conservative assignment was selected. Future efforts should seek to inform the selection of LUFs based on numerous DDIs and CDI field observations.

Table 5: Lane Utilization Factor Calculation* **

Turning Movements	Scenarios	Lane Utilization Factor (LUF) Calculations
Upstream Approaches: NBT1 / SBT2	LC1 (CDI), LC2, LC3	For the lanes utilized by vehicles prepositioning to make through movement at the downstream approach: $LUF = \frac{1}{\#\ of\ lanes\ on\ SBT1\ or\ NBT2}$, all lanes For the lanes utilized by vehicles prepositioning to make left-turn at the downstream approach: $LUF = \frac{1}{\#\ of\ lanes\ on\ SBL1\ or\ NBL2}$, all lanes
	LC1-DDI with shared lanes (3 lanes)	Let $x_T = [number\ of\ lanes\ on\ NBT1\ or\ SBT2] \times [through\ vehicle\ proportion]$ If $x_T < 1$, then $LUF = 1$, for lane 1 $LUF = 0$, for lane 2 If $1 \leq x_T \leq 2$, then $LUF = 1/x_T$, for lane 1 $LUF = (x_T - 1)/x_T$, for lane 2 If $x_T > 2$, then $LUF = 0.5$ for both lanes
		Let $x_L = [number\ of\ lanes\ on\ NBT1\ or\ SBT2] \times [left\text{-}turn\ \ proportion]$ If $x_L < 1$, then $LUF = 0$, for lane 2 $LUF = 1$, for lane 3 If $1 \leq x_L \leq 2$, then $LUF = (x_L - 1)/x_T$, for lane 2 $LUF = 1/x_L$, for lane 3 If $x_L > 2$, then $LUF = 0.5$ for both lanes

* Lanes are numbered from centerline to outside edge of roadway

** Table 5 continues in the next page

Table 5: Lane Utilization Factor Calculation (continue)*

Downstream Approaches: SBT1 / NBT2	LC1 (CDI), LC2, LC3	$LUF = \dfrac{1}{\#\ of\ lanes\ on\ SBT1\ or\ NBT2}$
	LC1-DDI with shared lanes (3 lanes)	For vehicles coming from cross street (SBT1 or NBT2): $LUF = LUF_{NBT1_{x_T}\ or\ SBT2_{x_T}}$ For vehicles coming from off-ramps (EBL1 or WBL2): $LUF = \dfrac{1}{\#\ of\ lanes\ on\ SBT1\ or\ NBT2}$
Downstream Approaches: SBL1 / NBL2	LC1 (CDI), LC2, LC3	$LUF = \dfrac{1}{\#\ of\ lanes\ on\ SBL1\ or\ NBL2}$
	LC1-DDI with shared lanes (3 lanes)	For vehicles coming from cross street (SBT1 or NBT2): $LUF = LUF_{NBT1_{x_L}\ or\ SBT2_{x_L}}$ For vehicles coming from off-ramps (EBL1 or WBL2): $LUF = \dfrac{1}{\#\ of\ lanes\ on\ SBL1\ or\ NBL2}$

* Lanes are numbered from centerline to outside edge of roadway

In determination of the arriving traffic volume at an approach potential upstream capacity constraints are considered. However, traffic volumes on downstream movements (SBT1, SBL1, NBT2, and NBL2) receive the throughputs of upstream movements (NBT1, EBL1, SBT2, and WBL2). Where the upstream intersection movement cannot process all the assigned traffic or when v/c ratios of upstream movements exceed 1, the downstream arriving volume is adjusted. It is assumed that the maximum throughput processed by the upstream approach is 95% of the capacity, and thus, the volume on downstream movements is adjusted as shown in Equation 3.

$$if\ v/c_U > 0.95, \qquad v_D = C_u \times 0.95 \times LUF \tag{3}$$

v/c_U = v/c ratio of an upstream movement

v_D = demand per lane of a downstream movement (vphrpln)

An interchange intersection v/c ratio is calculated based on the sum of the critical lane volumes in the critical path and the critical path capacity. Equation 4 calculates the critical lane volume of an intersection by summing the demand per lane of critical path phases.

$$v_{Node\ i} = \sum_{j=1}^{n} v_j \tag{4}$$

$Node\ i$ = selected intersection within the interchange

v_j = volume per lane of each movement within the critical path of the intersection (vphrpln)

n = number of phases within the critical path of the intersection

The intersection critical path capacity is calculated using Equation 5 based on the cycle length and total lost time per cycle. The DDI has two phases in a cycle critical path and the CDI has either two or three phases in a cycle critical path depending on the phase demands.

$$c_{Node\ i} = \frac{3600 - \left[\frac{3600}{C} \times (t_L \times N)\right]}{h} \tag{5}$$

$c_{Node\ i}$ = capacity per lane of the selected intersection (vphrpln)

C = cycle length of the intersection (seconds)

t_L = total lost time per phase, assumed as 4 seconds

N = number of phases in a cycle

h = saturation headway, assumed as 1.8 s/veh, (i.e., saturation flow of 2000 veh/hr/ln)

The intersection v/c ratio may then be calculated using the critical path volume and the critical path capacity. For this analysis, the interchange v/c ratio was set as the larger v/c ratio of two interchange intersections, as shown in Equation 6.

$$v/c_{interchange} = max(v/c_{Node1}, v/c_{Node2}) \tag{6}$$

3.3.4.2 Comparative Study

Calculated v/c movement and interchange ratios are populated into a tabular format and color-coded to present the difference in v/c ratios between the CDI and DDI scenarios using Microsoft Excel and Visual Basic (VB) scripts (APPENDIX B). The color schematics of the color-coded spreadsheet for v/c ratios is presented in Table 6. The v/c ratios are then plotted to help visualize the differences between the CDI and DDI performance over different demand and through/left proportions. Using these tables and plots, patterns in the v/c ratios and relative performance between the interchange configurations are explored.

Table 6: Color schematics of Color-Coded Spreadsheet for v/c ratios

Cell Color	Meaning
Green	Lower v/c ratio with difference > 0.2
Yellow	Greater v/c ratio with difference > 0.2
Red	v/c ratio ≥ 0.95

3.3.5 Microscopic Simulation Study

The second step in the sensitivity analysis is the microscopic simulation study using VISSIM for selected combinations of traffic volumes and through/left proportions to confirm the observations from the CLV analysis. The CLV study alone is insufficient to evaluate the CDI and DDI operational performance as the v/c ratio does not present a complete operational picture as discussed in the literature review. Therefore, the VISSIM simulation study, which allows for the estimation of numerous operational parameters, is used to complement the CLV study. Similar to the CLV analysis the signal timing plans are optimized using Synchro are used in VISSIM simulation network. As the simulation study is more time-consuming than the CLV analysis, only selected case studies are tested using VISSIM. Table 7 and Table 8 below list selected demand scenarios and through/left proportions tested in this microscopic simulation study for all tested lane configurations. These scenarios were selected to represent a cross section of the scenarios in the CLV study.

Table 7: Selected demand scenarios for the simulation study

Cross street Volume (vph)	Off-Ramp Volume (vph)		
	Low	**Medium**	**High**
1500	500	1100	1800
2100	500	1100	1800
2500	500	1100	1800

Table 8: Selected through/left proportions for the simulation study

Through/Left Proportions	
Through	**Left**
1	0
0.9	0.1
0.7	0.3
0.5	0.5
0.3	0.7
0.1	0.9
0	1

3.3.5.1 VISSIM Model

As with the CLV analysis the CDI and DDI VISSIM lane configurations and geometric designs are developed based on the Jimmy Carter Boulevard and I-85 interchange. Cross street grades are assumed as zero and grades on off-ramps were measured from the field (1.5% within 300ft of the cross street signal and 5.0% for the rest of the segment). Single vehicle input, defined as number of vehicles input into the network per hour (vph), was used for each simulation period to minimize the variability in the data from changing traffic demands over time. Again, as with CLV analysis, the study area covers the interchange segment, including off- and on-ramps, bridge segment, and the cross streets approaches to the interchange. Figure 11 and Figure 12 show sample CDI and DDI VISSIM models with the existing lane configuration (LC1). As seem, the primary difference between two models is the bridge segment, where the DDI model has crossovers at the two intersections. The LC2 and LC3 configurations as discussed in the CLV section are based on these initial VISSIM models.

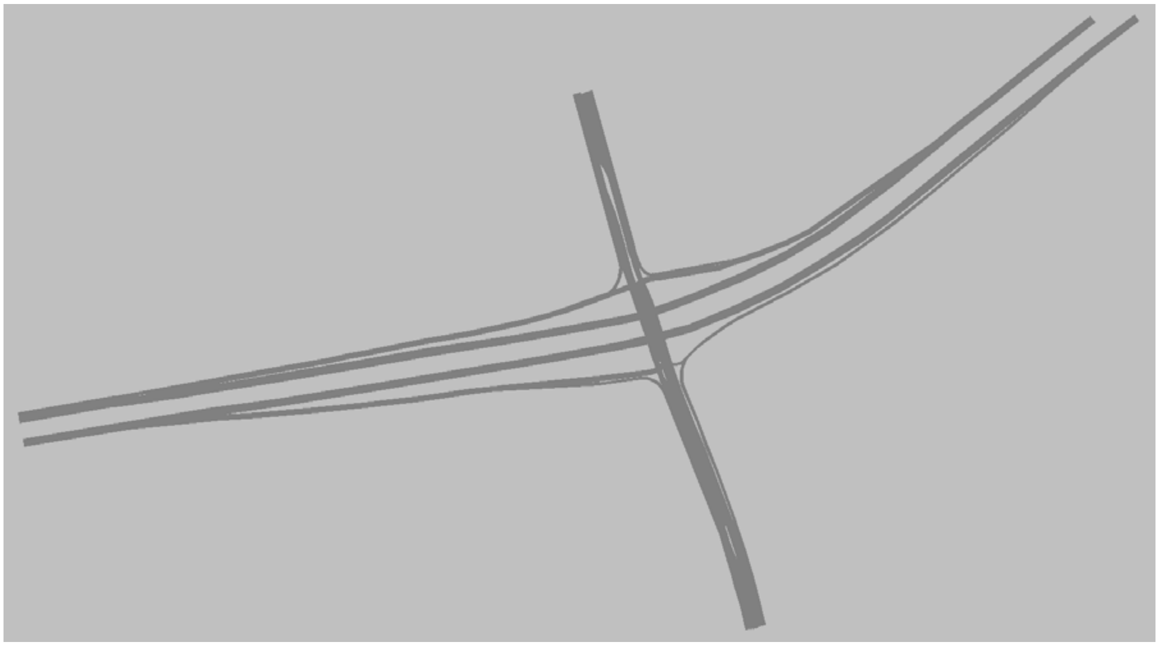


Figure 11: VISSIM model for the Conventional Diamond Interchange (LC1)

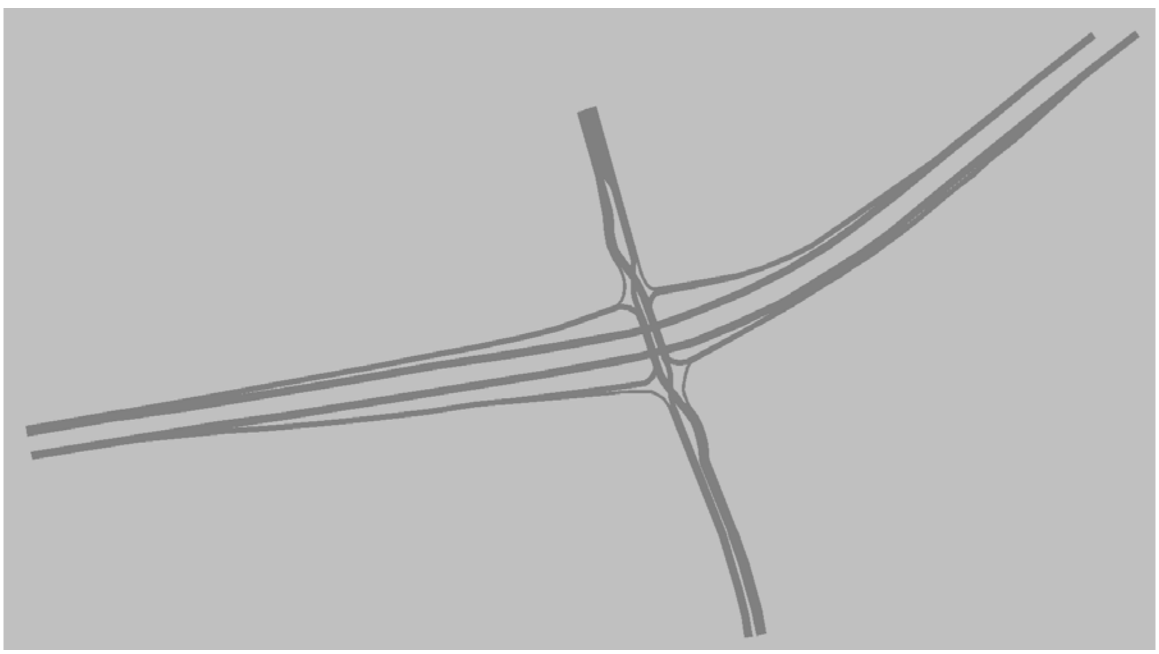


Figure 12: VISSIM model for the Diverging Diamond Interchange (LC1)

The study used the default VISSIM vehicle composition with 5% heavy vehicle. With the assumption of approximate turning speed of 25 mph, reduced speed zones were implemented at turning links with speed range of 20 to 30 mph. Priority rules were implemented at the intersections to prevent vehicles from driving through other vehicles blocking the intersection. The simulation time of VISSIM models for each traffic scenario is 4,500 seconds. The first 900 seconds of the simulation is allotted to allow the model fill and reach steady state (if possible). Performance metrics from the fill time are not included in the analysis. Therefore, data is collected for 3,600 seconds, with 300 second bin aggregations. Ten simulation replications were conducted for each traffic scenario, with different seeds to provide variation in arrival patterns and network traffic flow. The simulation runs and data collection were automated using Microsoft Visual Studio with VB scripts (APPENDIX C).

Performance measures collected from the simulation study are average delay per vehicle, average travel time per vehicle, average number of stops per vehicle, queue length and throughput on each approach, and x- and y-coordinates of individual vehicles processed. R scripts are used to organize and summarize collected performance measures. The average delay per vehicle for each approach and the entire route are populated in Excel spreadsheets, enabling the comparisons between interchange configurations and demand scenarios.

3.4 Implementation

This section describes the sensitivity analysis implementation process, providing additional detail regarding inputs, spreadsheets, and software utilized to analyze the operational performance of the interchange configurations.

3.4.1 *Synchro Signal Optimization*

For each scenario traffic demand, through/left proportion, and lane configuration, an optimal signal timing plan was determine using Synchro. Synchro exports the signal timing parameters to a CSV file. Separate CSV files were created for each lane configuration tested. Each timing plan of each subsequent Synchro scenario run is appended to the end of the CSV file. A screen capture of an exported signal plan in a CSV file format is shown in Figure 13. Each signal plan (PLANID) is named after the combination of cross street and off-ramp volumes, and the left-turn proportion. For example, the plan ID of 100020050 represents a 1000 vph cross street volume, 200 vph off-ramp volume, and 50% left-turn proportion. After all the optimized signal timings are exported to CSV files, signal plans in the CSV files are exported to the CLV spreadsheet under "Signal Timing" tab into a format suitable for the analysis using a VB script (APPENDIX B). Figure 14 shows the screen capture of the signal plans reorganized in the CLV spreadsheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Timing Plans																	
2	PLANID	INTID	S1	S2	S3	S4	S5	S6	S7	S8	CL	OFF	LD	REF	CLR	NOTE	RUNDATE	RUNTIME
3	10002000	4		31		39		39			70	5		2		From Sync	#########	#########
4	10002000	6		40				30		40	70	68		2		From Sync	#########	#########
5	100020010	4		28		32		32			60	5		2		From Sync	#########	#########
6	100020010	6		33				27		33	60	0		2		From Sync	#########	#########
7	100020030	4		25		25		25			50	0		2		From Sync	#########	#########
8	100020030	6		26				24		26	50	48		2		From Sync	#########	#########
9	100020050	4		27		23		23			50	49		2		From Sync	#########	#########
10	100020050	6		24				26		24	50	0		2		From Sync	#########	#########
11	100020070	4		29		21		21			50	48		2		From Sync	#########	#########
12	100020070	6		22				28		22	50	0		2		From Sync	#########	#########
13	100020090	4		32		18		18			50	44		2		From Sync	#########	#########
14	100020090	6		19				31		19	50	0		2		From Sync	#########	#########
15	1000200100	4		40		20		20			60	22		2		From Sync	#########	#########
16	1000200100	6		21				39		21	60	0		2		From Sync	#########	#########

Figure 13: Optimized signal timings exported to a CSV file

	A	B	C	D	E	F	G	H	I	J	K	L
1							DDI					
2	Code	NBT1	EBL1	SBT1	EBR1	NBT2	WBR2	SBT2	WBL2	CL	Offset_NB	Offset_SB
3	10002000	31	39	39	17	40	16	30	40	70	5	68
4	100020010	28	32	32	14	33	13	27	33	60	5	0
5	100020030	25	25	25	11	26	10	24	26	50	0	48
6	100020050	27	23	23	13	24	12	26	24	50	49	0
7	100020070	29	21	21	15	22	14	28	22	50	48	0
8	100020090	32	18	18	18	19	17	31	19	50	44	0
9	1000200100	40	20	20	26	21	25	39	21	60	22	0
10	10005000	25	35	35	11	36	10	24	36	60	6	0
11	100050010	26	34	34	12	35	11	25	35	60	7	0
12	100050030	23	27	27	9	28	8	22	28	50	4	0
13	100050050	25	25	25	11	26	10	24	26	50	1	0
14	100050070	27	23	23	13	24	12	26	24	50	22	0
15	100050090	29	21	21	15	22	14	28	22	50	20	48
16	1000500100	30	20	20	16	22	14	28	22	50	21	0
17	10008000	24	36	36	10	37	9	23	37	60	7	0
18	100080010	24	36	36	10	36	10	24	36	60	6	0
19	100080030	22	28	28	8	29	7	21	29	50	5	0
20	100080050	24	26	26	10	27	9	23	27	50	2	0
21	100080070	25	25	25	11	26	10	24	26	50	24	48
22	100080090	27	23	23	13	25	11	25	25	50	25	0
23	1000800100	27	23	23	13	25	11	25	25	50	25	0
24	15005000	33	47	47	19	48	18	32	48	80	7	0
25	150050010	34	46	46	20	47	19	33	47	80	7	0
26	150050030	33	37	37	19	38	18	32	38	70	5	0
27	150050050	30	30	30	16	30	16	30	30	60	1	0
28	150050070	28	22	22	14	23	13	27	23	50	22	0
29	150050090	31	19	19	17	20	16	30	20	50	19	49

Figure 14: Signal plans reorganized in the CLV spreadsheet

3.4.2 CLV Study and Comparative Analysis

After importing the DDI and CDI interchange signal plans for all volume-proportion combinations and lane configurations in the “Signal Timing” tab of the CLV spreadsheet (each lane configuration has separate CLV workbook), CLV analysis is conducted to calculate v/c ratios for each scenario. The v/c ratio for each volume-proportion combination is calculated in “DDI_CLV” and “CDI_CLV” worksheets in the workbook. Each sheet consists of vehicle input, through/left proportion, route decision, phase diagram, proportional phase timing, volume set for Synchro, traffic demand and lane numbers on each approach, optimized timing from Synchro, approach capacity, and v/c ratio calculation. Cells in the right-top corner of the spreadsheet contain selected cross street and off-ramp volumes, and through/left proportions to be tested. Figure 15 below shows the screen capture of “DDI_CLV” worksheet. A VB script (APPENDIX B) automatically inputs cross street and off-ramps volumes and through/left proportions into the cells and exports calculated v/c ratios into the “Color Coded” worksheet, which contains color coded tables and plots of the CDI and DDI v/c ratios, utilizing the color schematics described in Table 6. These tables and plots are used to analyze the conditions in which one interchange design outperforms the other.

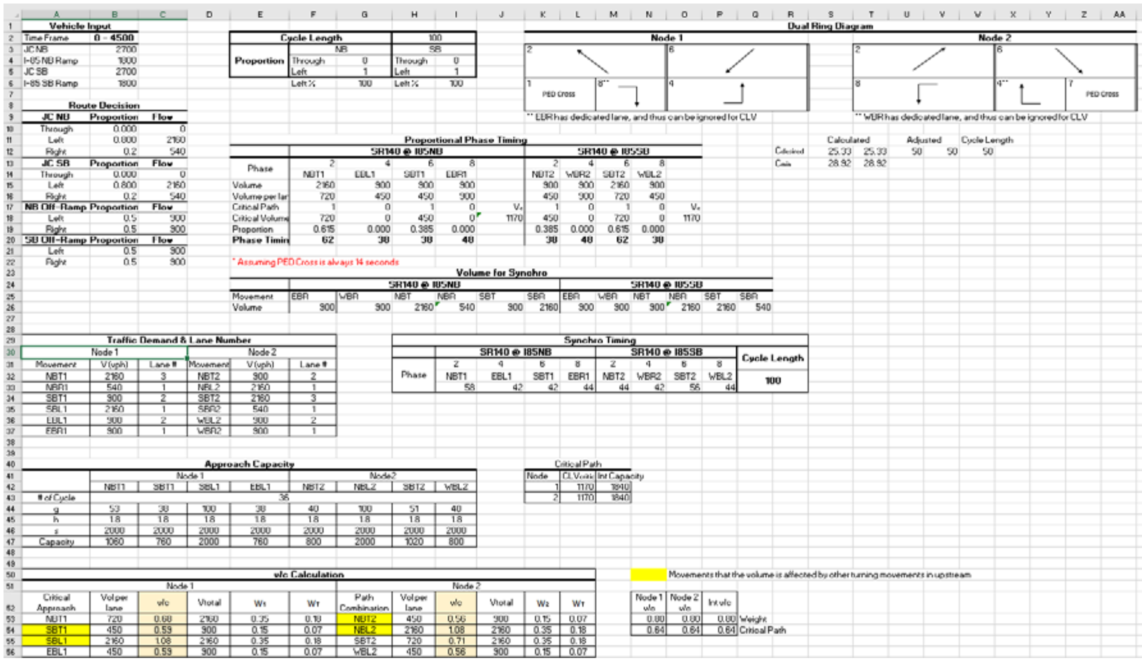


Figure 15: Spreadsheet for v/c ratio calculation for the CLV analysis

3.4.3 VISSIM Simulation Analysis

After completion of the CLV analysis, the VISSIM microscopic simulation study is undertaken. Based on the CLV findings, cross street and off-ramps volumes representing low, medium, and high traffic demand scenarios are selected for the simulation case study.

As stated previously, CDI and DDI VISSIM models are created based on the geometry from a Google Maps® aerial of the Jimmy Carter Boulevard and I-85 interchange. Signal timing files (RBC files) are manually created for each traffic scenario using the signal plans from Synchro. Developed Microsoft Visual Studio VB script (APPENDIX C) automates the process to call, input, and run VISSIM models and to collect performance measures, including delay, travel time, throughput, queue length, and x- and y-coordinates of individual vehicles. Ten simulation runs were conducted for each volume-proportion set and average delay per vehicle data is calculated based on the weighted average of these ten simulation runs using the R script as shown in Equation 7.

$$average\ delay\ per\ vehicle = \frac{\sum_{i=1}^{n}(d_i \times v_i)}{\sum_{i=1}^{n} v_i} \tag{7}$$

n = number of simulation runs conducted (10 runs)

d_i = delay per vehicle at nth simulation run

v_i = throughput on an approach at nth simulation run

Average delay per vehicle and average throughput data for each lane configuration are organized in the "VISSIM Output Analysis" worksheet and plotted for each turning movement to enable the comparison of the CDI and DDI operational performances across the various scenarios. Each worksheet in the LC1, LC2, and LC3 workbooks contains the delay and throughput data from simulation study of the respective configuration.

CHAPTER 4. RESULTS AND DISCUSSIONS

This chapter summarizes, compares, and evaluates results from the CLV analysis and the VISSIM simulation study.

4.1 CLV Analysis Results

The CLV study calculates CDI and DDI v/c ratios at different traffic demands and turn movement ratios. Calculated v/c ratios are populated into color-coded spreadsheets and plots to present the CDI and DDI operational performance. Figure 16, Figure 17, and Figure 18 plot the difference CDI v/c – DDI v/c for each lane configuration (LC1, LC2, and LC3) and traffic demand scenario. Values in the legend represent cross street and off-ramps demands, i.e. 2100/500 is interpreted as a cross street demand of 2100 vph and an off-ramp demand of 500 vph. Refer to APPENDIX D for all detailed results of color-coded tables and plots developed using the CLV method.

For the existing lane configuration (LC1), the CDI favors over the DDI (v/c ratios of the CDI are lower than those of the DDI, thus the difference in v/c ratios is negative) when the cross street left-turn proportion is below 30%. The two interchange configurations experience similar v/c ratios at the proportion of 70/30, and the DDI outperforms the CDI at left-turn proportions exceeding 50% of total demand. Also, for a given through/left proportion the v/c ratios difference consistently increases as the demands increase, supporting the benefits of the DDI under higher demands. Thus, at the lower left-turn proportions, while the CDI may have lower v/c ratios, the relative advantage over DDI decreases as demands increase; likewise, at higher left-turn proportions, the advantage of the DDI is amplified at higher demands. For the LC2 scenario (i.e. fewer lanes than LC1) the DDI and CDI have a similar performance as that of LC1. The CDI again has superior operational performance than the DDI until the left-turn proportion reaches 30% of total demand, at which point performance is similar. At left turn percentages of 50% and above the DDI outperforms the CDI, although the magnitude of the difference is not as large. The LC3 plot, the largest bridge cross section (8 lanes) tested in this study, shows a slight shift, with the CDI and DDI having similar performance at the through/left ratio of 50/50 with the CDI generally providing better service at lower left turn proportions and the DDI at higher left turn proportions. This change is expected as the CDI capacity is more sensitive to the number of lanes, thus when the number of lanes increases, the CDI operational performance will see greater improvements than the DDI (Hughes et al., 2010).

From the color-coded tables comparing the CDI and DDI v/c ratios by individual turning movement (APPENDIX D), it is seen that SBT1 and NBT2, the through movements exiting the bridge, as expected, experience better operations (lower v/c ratios) on the CDI than on the DDI, in most traffic scenarios. This is primarily due to the CDI through movement having concurrent signal timing, whereas these movements operate in a split phase pattern on the DDI. However, it is also seen that the DDI provides superior service to the left-turn movements from cross streets to the on-ramps and the left-turns from off-ramps to the bridge (SBL1, NBL2, EBL1 and WBL2) in most traffic scenarios. This derives from the DDI free flow left-turn movements, an overall reduction in lost time, and the off-ramp movements in the DDI running concurrent with cross street through movements often resulting in a higher effective green for this movement than in the CDI.

Overall, as expected the CDI has a tendency to favor cross street through movements while a DDI favors left-turn movements.

Figure 16: Difference in v/c ratios between CDI and DDI for LC1 at different traffic demands and through/left proportions

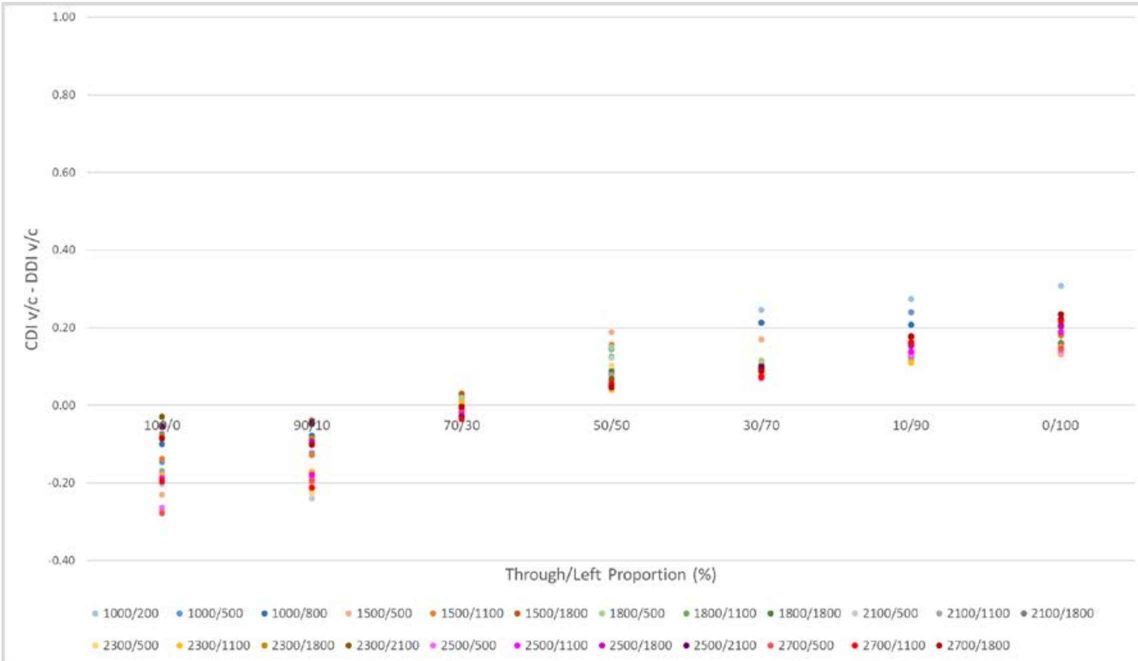


Figure 17: Difference in v/c ratios between CDI and DDI for LC2 at different traffic demands and through/left proportions

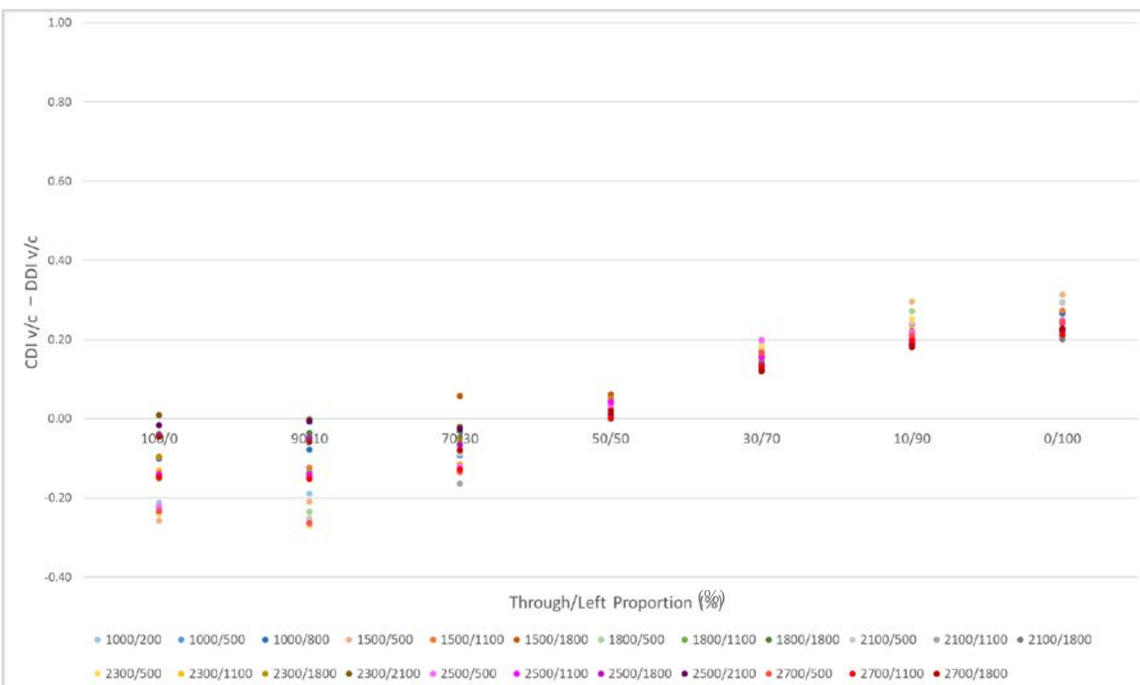


Figure 18: Difference in v/c ratios between CDI and DDI for LC3 at different traffic demands and through/left proportions

4.2 Microscopic Simulation Study Results

As part of the VISSIM simulation portion of this study various performance measures were collected including delay, throughputs volume, number of stops, and queue length on each approach. For the following discussion the primary performance measures discussed are the average delay per vehicle in the interchange, aggregated over all movements, and the interchange throughput, as these were found to provide the best representation of overall performance. Refer to APPENDIX E for all detailed results of CDI and DDI average delay per vehicle and throughput data on individual turning movements.

4.2.1 Lane Configuration 1 (LC1)

The first lane configuration tested in this study is LC1, i.e., the before-and-after models of the Jimmy Carter Boulevard and I-85 interchange. Figure 19, Figure 20 and Figure 21 below plot the average delay per vehicle and the throughput of the CDI and the DDI for the studied traffic volumes and turn movement ratios. Values in the legend represent the off-ramp demands tested for the cross street demand.

From these plots, it is noted that the CDI generally performs better or at a similar level to the DDI at left-turns proportion below 30% of total traffic demand, and the DDI outperform the CDI when the left-turn proportion is 50% or greater. These results are similar to the CLV findings. Although, at the higher left-turn proportions the CDI delays are significantly higher than those seen in any through/left proportion on the DDI. These patterns are also noted in the throughput data. At the lower left-turn proportions, the CDI tends to satisfy demand; whereas, the DDI is less likely to satisfy demand, particularly at higher overall demands. When the left turn proportion exceeds 50% the CDI is often unable to process the demand, failing to serve a significant portion of the demand at the higher volume levels, whereas the DDI reliably processes the full demand.

The relative difference in performance between the CDI and the DDI at the through/left proportions of 50/50 or more is greater in the simulation study than those found in the CLV analysis, especially at higher cross street demands. This is because the CLV method does not does not reflect the synchronization of intersections in the interchange or the complex lane utilizations seen in the VISSIM simulations. These differences are particularly witnessed on the SBT1 and NBT2 approaches, i.e., the through movements exiting the bridge. These movements tend to favor CDIs in the CLV analysis but are found to be similar between the CDI and the DDI in the simulation study. It is also seen in the simulation plots that the left-turn proportion at which the DDI becomes the favored alternative is higher for lower cross street demands.

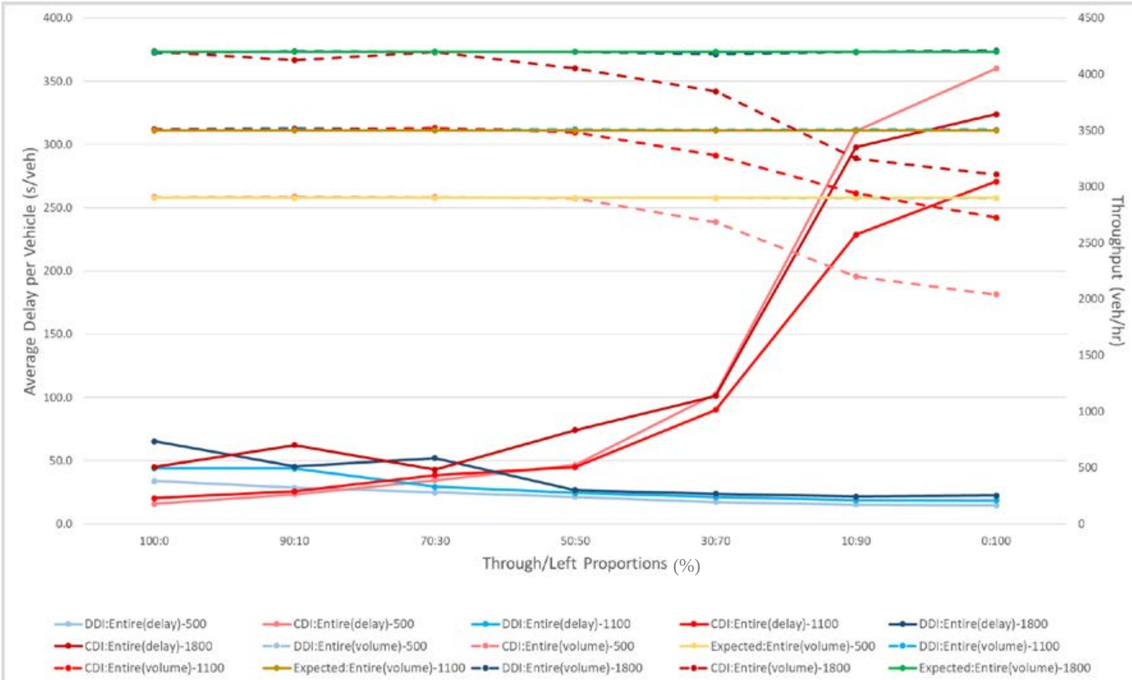


Figure 19: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

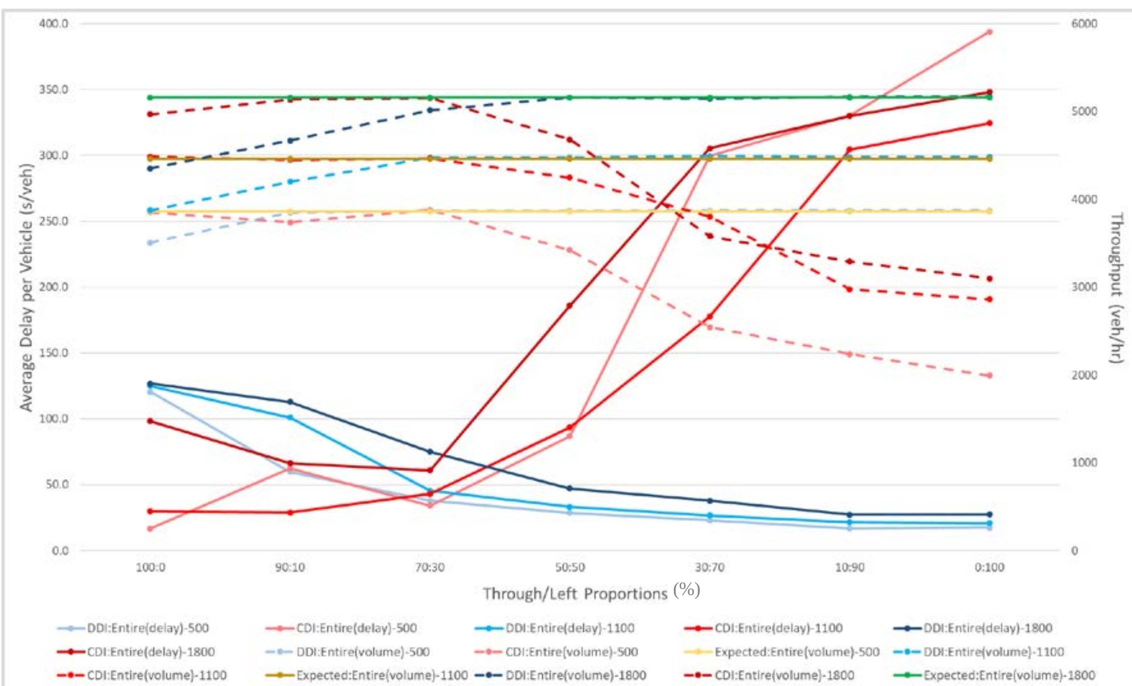


Figure 20: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

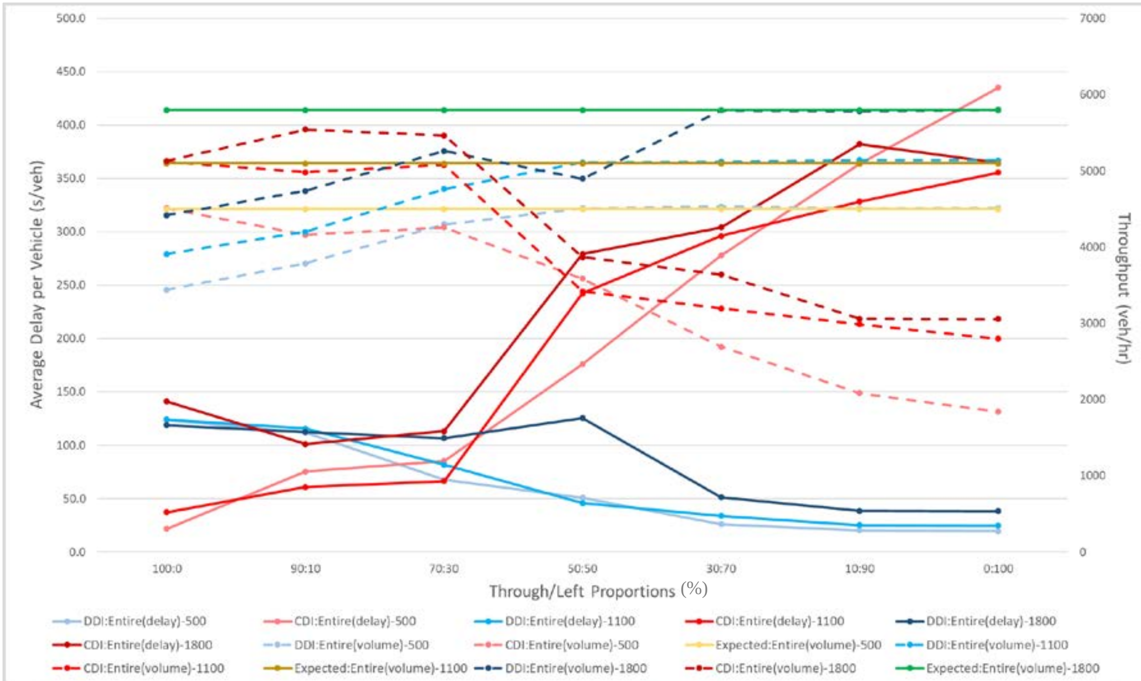


Figure 21: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

4.2.2 Lane Configuration 2 (LC2)

The second lane configuration tested, LC2, has three entering lanes on the cross streets approaches and one left-turn and two through lanes on each direction of the bridge. Figure 22, Figure 23 and Figure 24 below plot the average delay per vehicle and the CDI and DDI throughput at different traffic demands and turn movement ratios. For all three cross street demands tested, the CDI only clearly outperforms the DDI in the 10% left case, and the average delay per vehicle of the CDI starts to exceed that of the DDI at the left-turn proportion of 30%. This trend is same as what was found in the CLV analysis, where the difference in CDI and DDI v/c ratios starts to turn positive (v/c ratios of CDIs are higher than that of DDIs) at through/left proportion of 70/30. As with LC1, it is seen in the simulation plots that the left-turn proportion at which the DDI becomes the favored alternative is higher for lower cross street demands.

Unlike the results found in the CLV analysis where the magnitude of difference in v/c ratios between the CDI and DDI configuration is smaller for LC2 than LC1, the results from the simulation study show no meaningful change in differences in average delay per vehicle between the LC1 and LC2 interchange configuration.

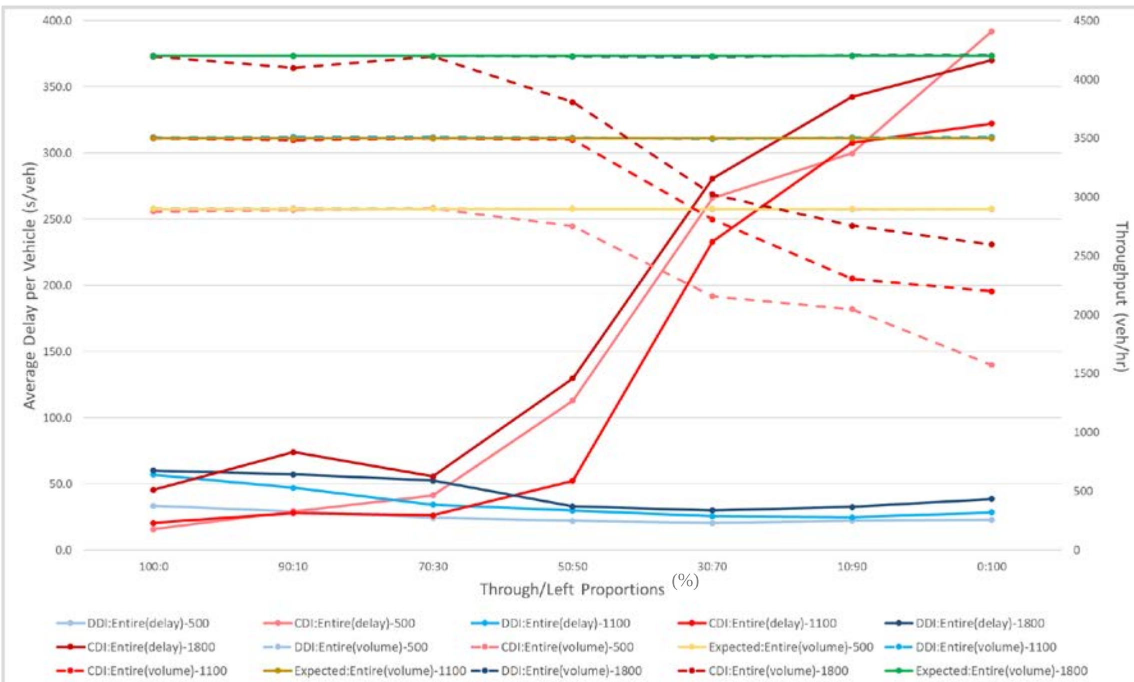


Figure 22: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

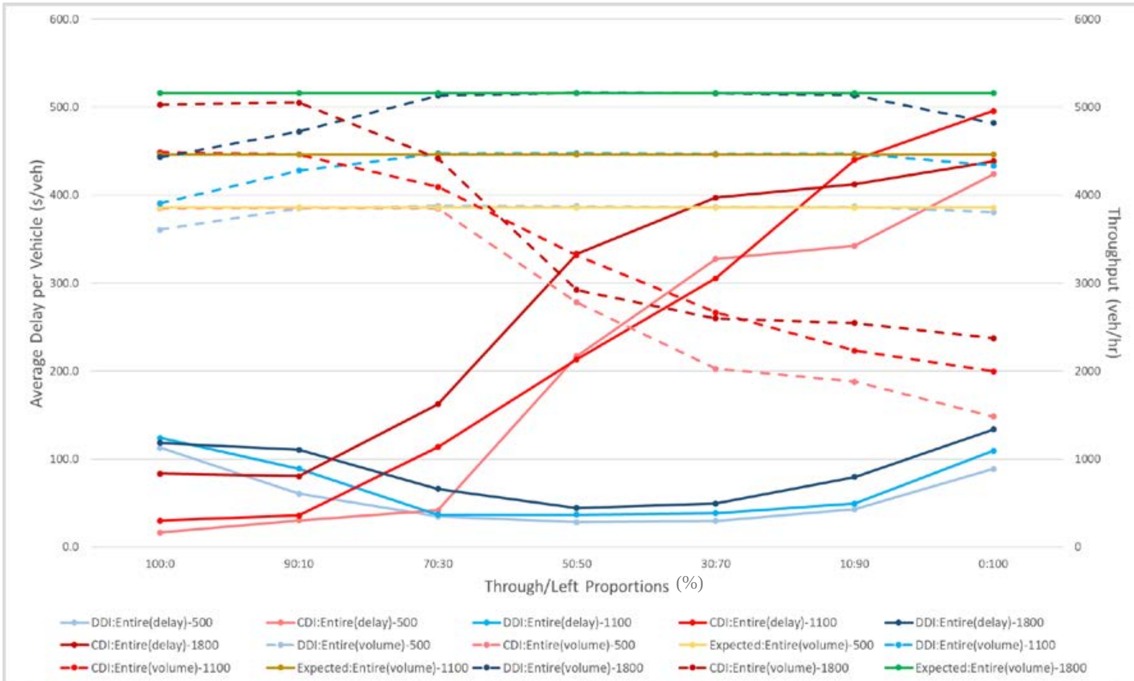


Figure 23: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

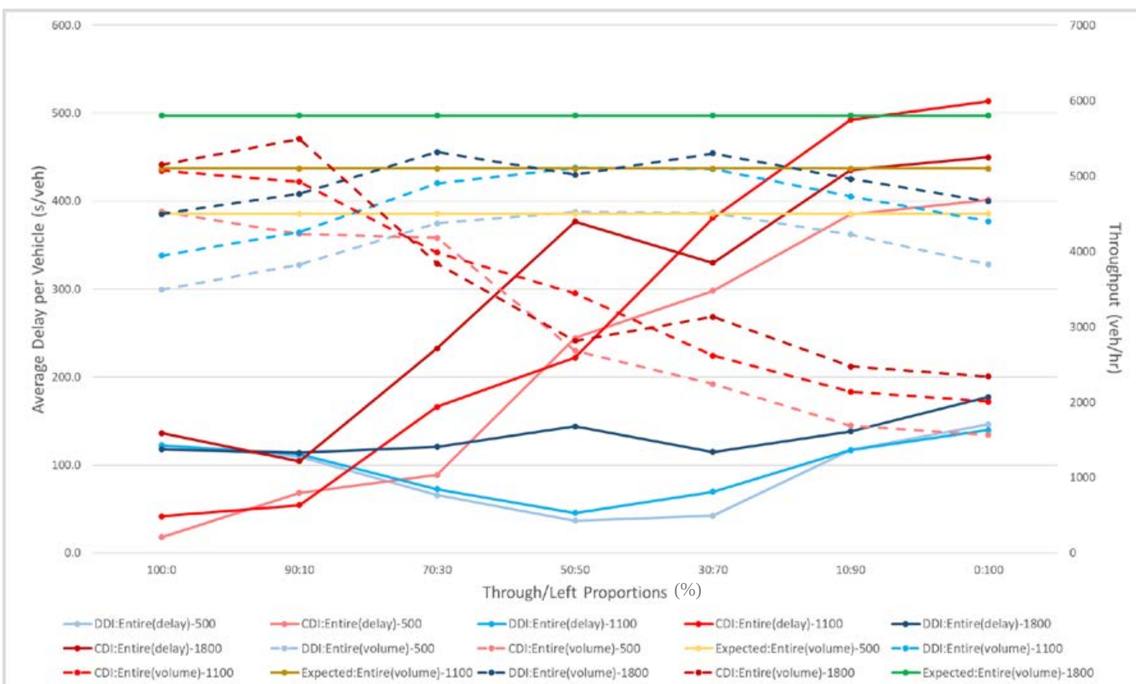


Figure 24: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

4.2.3 Lane Configuration 3 (LC3)

The third lane configuration tested, LC3, has the most lanes, with four entering lanes on the cross street approaches and two left-turn and two through lanes on the bridge. Figure 25, Figure 26 and Figure 27 below plot the average delay per vehicle and the interchange throughput at different traffic volumes and turn movement ratios. The CDI performs better or at a similar level to the DDI until the left-turn proportion reaches 50%. The DDI starts to outperform the CDI for the left-turn proportion of 70%. Similar to the CLV results, the simulation results show that the CDI and DDI v/c ratios are similar at the 50/50 through/left proportion. LC3 has the highest left-turn proportion at which the DDI becomes the favored alternative, aligning with the CLV finding that the CDI and DDI relative operational performance are partially dependent to total available cross section. Again, as with LC1 and LC2, it is seen in the simulation plots that the left-turn proportion, at which the DDI becomes the favored alternative, is higher for lower cross street demands, indicating that the CDI performs better at lower traffic volume.

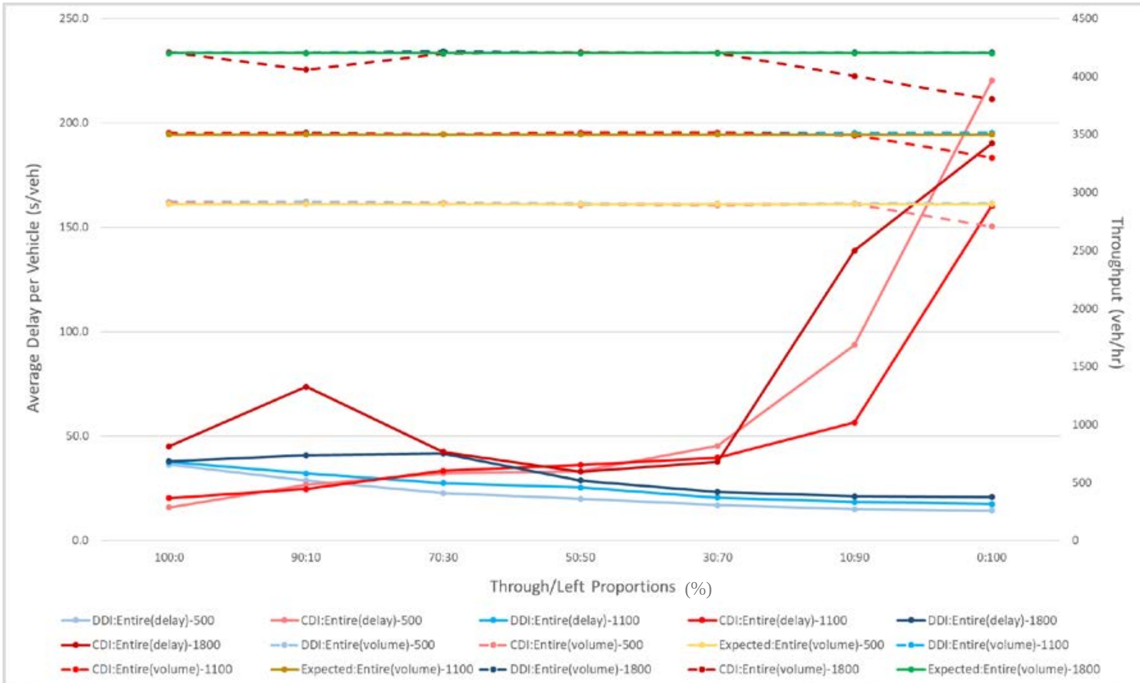


Figure 25: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

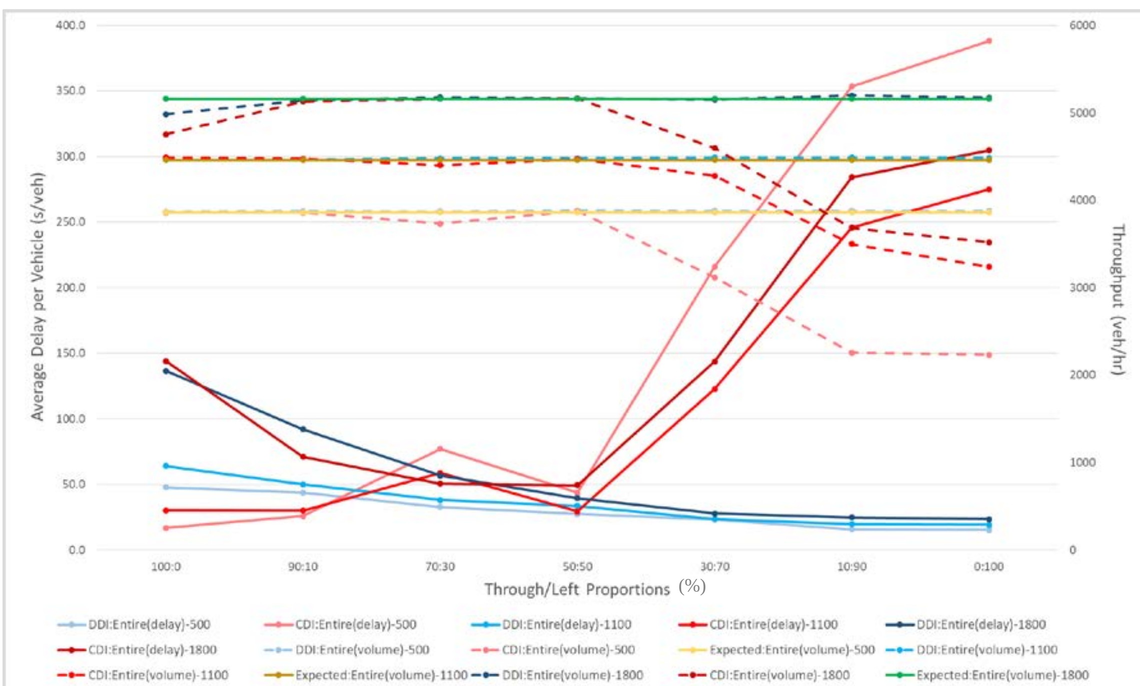


Figure 26: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

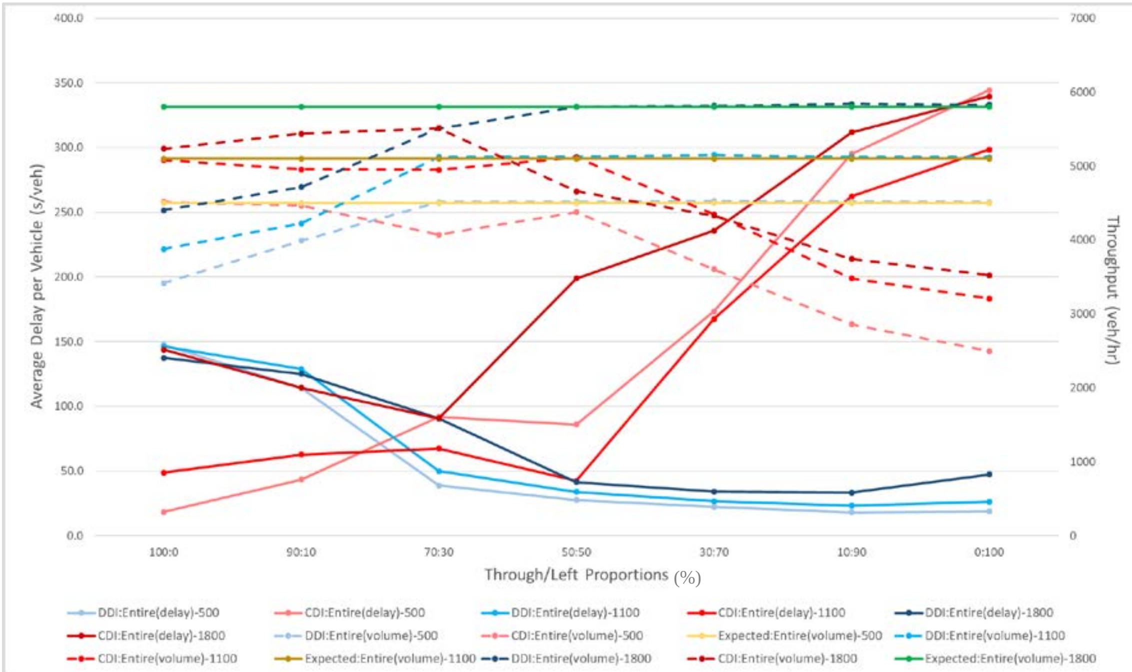


Figure 27: DDI and CDI average delay per vehicle and interchange throughput with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

4.3 Discussion and Evaluation of the Results

Based on the results from the CLV analysis and VISSIM simulation study, it is found that CDIs have better operational performance than DDIs at higher through and lower left-turn proportions, while DDIs perform better in the opposite condition. The through/left proportion at which the CDI and DDI configurations had similar performance is dependent on cross street cross sections, and total demand. As the number of lanes on the cross street increases, especially left-turn lanes, the left-turn proportion required for the DDI to provide favorable performance increases. For the lane configurations tested in this study the CDIs and DDIs were found to have similar performance in the through/left proportion range of 70/30 to 50/50. Where the left turn proportion was below 30% the

CDI tended to offer better performance and where the left-turn proportion exceeded 50% of the total traffic demand the DDI tended to offer better performance. The most significant operational benefits of DDI configuration are found on the cross street to on-ramp left-turn movements and freeway off-ramps on to the cross street bridge. CDI configurations tended to provide better through movement operations.

The CDI configuration was also found to perform better at lower cross street demands at a given through/left proportion, while the operational performance of the CDI degrades faster than that of the DDI at higher cross street demands. These results align well with findings from previous studies that the CDI performs better or similar to the DDI at low-to-medium volumes, and the DDI outperform the CDI at higher traffic volumes (Bared et al., 2005; Edara et al., 2005; Sharma & Chatterjee, 2007; Speth, 2008). However, the impact of off-ramp demands on the operational performance of CDIs and DDIs is inconclusive due to the mixed results found in this study.

The overall comparative CDI and DDI operational performance trends observed are similar in both the CLV and simulation methodologies, with some difference in the observed performance difference magnitudes and at the individual movement level. In the CLV analysis, the CDI configuration is found to have better performance on the SBT1 and NBT2 movements in most traffic scenarios. However, these movements have no meaningful operational difference in the simulation study. This is primarily due to the CLV method’s inability to capture the effect of synchronization between intersections and difference in lane utilizations between the two methods.

CHAPTER 5. CONCLUSIONS AND FUTURE RESEARCH

5.1 Summary of Findings

The operational performance curves developed in this study for CDI and DDI interchange configurations are able to support planning and decision-making procedures for interchange improvement projects and should contribute to the development of criteria for the selection, planning, and design of CDI to DDI interchange conversions. From the sensitivity analysis of the CDI and DDI interchange configurations using both CLV and microscopic simulation, the two configurations were seen to provide similar performance (or alternate configuration which provided better service) at left-turn proportions between 30% and 50% of the total traffic demand, dependent on the interchange lane configuration and total demand. For instance, the left-turn proportion at which a DDI configuration outperforms the CDI configuration increases as the number of lanes on the cross street cross section increases. The CDI also performs better at lower cross street demands, although its operation degrades faster than that of the DDI at high cross street demands. In the current study, the impact of off-ramp demands on the CDI and DDI operational performance is inconclusive.

In conclusion, a CDI is likely the preferred alternative at locations with low traffic volumes and left-turn traffic proportions below 30% of the total traffic demand, and a DDI is likely the preferred alternative at locations with higher traffic volumes and left-turn proportions exceeding 50% of the total demand.

5.2 Limitations in the Study

There are a few limitations in this study that can be improved in future research efforts. First, as noted by Chlewicki (2011) and Schroeder et al. (2014), the CLV method oversimplifies the operational performance of an interchange and an intersection. It tends to overestimate the performance of the CDI due to its inability to account for intersection signal synchronization. As a result, some discrepancies in results between the CLV analysis and the simulation study were found, especially on the through movements exiting the bridge (SBT1 and NBT2). In both the CDI and DDI configurations, the VISSIM simulations show relatively constant, low delays on the through movements exiting the bridge with good signal coordination between the intersections. However, the CLV method does not reflect this intersection synchronization, resulting in higher v/c ratios for the same movements on DDIs.

In addition, the CLV analysis does not capture the impact of significant queuing or spillback. For instance, on the DDI configuration the freeway on-ramp from the cross street is assumed to be uninterrupted and thus free flow. However, it is possible the free flow traffic could lead to downstream congestion on the ramp, either when merging with right-turning vehicles from the cross street or merging onto the freeway. Spillback, potentially to the bridge, is not reflected by the CLV method. This problem was observed during peak hours at the interchange of Jimmy Carter Boulevard and I-85. Therefore, it is important for engineers and planners to understand the potential broader impact of the improved DDI left-turn accommodation, and that bottlenecks may not be eliminated, only moved to new locations. This study also did not take into account adjacent intersections. Adjacent intersections may have significant impacts on the interchange operation. However, adjacent intersections were neglected in this study to minimize the number of confounding variables in the operational analysis.

During the field observation at the study interchange, it was observed that a large truck, exceeding 50ft in length, occupied both off-ramp lanes while turning onto the bridge. This behavior is not replicated in the current CLV analysis or VISSIM simulation. However, when designing the interchange, consideration must be given to the potential reduction in capacity due to tight curve radii. Future efforts may expand the current VISSIM model to explore this impact.

Lastly, this study only examined balanced volume conditions, i.e. similar demand from both cross street approaches. It is desirable to expand the analysis to explore the impact of unbalanced volumes.

5.3 Potential Future Research

This study provides a foundation for developing more detailed standards and guidelines for the implementation of a DDI based on various lane configurations and traffic conditions. However, based on the limitations found in this study, it is recommended to conduct the simulation study for both balanced and unbalanced traffic conditions and expand the study area to include adjacent intersections for a more thorough analysis in future studies.

It is also recommended to study the operational impact of large trucks (exceeding 50ft in length) with a turning radius that would require multiple lanes to enter the bridge. This will provide a better understanding of the impact of DDI geometrics in accommodating heavy-trucks. Adding ramp meters into simulation models will capture the impact of spillback from on-ramps to the bridge. This will provide more reliable performance data where freeway congestion may impact the cross street operations.

Lastly, improved lane utilization factors, in addition to left-turn and heavy vehicle adjustment factors, should be developed for the CLV analysis to better replicate the potential variations in field conditions. These additions to the future study will provide more reliable and accurate data in analyzing the DDI operational performance.

APPENDIX A. COST OF CONSTRUCTION OF DIVERGING DIAMOND INTERCHANGES AND ALTERNATIVE DESIGNS AT FOUR LOCATIONS

Following Table A-1 compares the construction costs of DDIs and other alternative designs at four locations in the United States (Chlewicki, 2014). This table shows large cost saving from constructing DDIs over other alternatives in many cases.

Table A-1: Cost of construction of Diverging Diamond Interchanges and alternative designs at four locations

Interchange	Location	DDI Cost (real or estimated, $Million)	Alternative Design Cost ($Million)	Cost Saving (%)
I-44 @ Route 13	Springfield, MO	3.2	> 10	~70
I-435 @ Front Street	Kansas City, MO	6.7	CID: 11. 4 SPUI: 25	~75
SR_265 @ SR-62	Utica, IN	52	118	~55
I-590 @ Winton Road	Brighton, NY	3~4	SPUI: 10 Triple Left Diamond: 13.6	~75

APPENDIX B. EXCEL MACRO VISUAL BASIC SCIPTS

This appendix provides Visual Basic scripts used in the Macro functions of Microsoft Excel to automate the data analysis and organization processes for the CLV analysis.

A.1 Optimized Signal Timing Relocation

Following VB script relocates the optimized signal timing plans from Synchro to the “Signal Timing” worksheet under the CLV workbook into a format that is suitable for v/c ratio calculations.

```
Sub SynchroCDITimingFill()

Dim CLVwbk As Workbook
Dim CLVSheet As Worksheet
Dim Timingwbk As Workbook
Dim TimingSheet As Worksheet
Dim testval

Set TimingSheet = Sheets("Timing")
Set    CLVwbk    =    Workbooks.    Open("C:\Users\spark365\Documents\Sung    Jun
Park\Research\DDI\After\DDI Final\CLV Method\CLV Spreadsheet LC2. xlsm")
Set CLVSheet = CLVwbk. Sheets("Signal Timing")
Dim rownumber As Long

rownumber = (TimingSheet. Range("A1", TimingSheet. Range("A1"). End(xlDown)). Rows.
Count) - 2
Planrow = 1 'count for rows of each signal plan

For PlanID = 1 To rownumber

    ICode = Cells(2 + PlanID, 1)
    IntID = Cells(2 + PlanID, 2)

    If IntID = 4 Then 'NB intersection
        Phase1 = Cells(2 + PlanID, 3) 'SBL1
        Phase2 = Cells(2 + PlanID, 4) 'NBT1
        Phase6 = Cells(2 + PlanID, 8) 'SBT1
        Phase8 = Cells(2 + PlanID, 10) 'EBL1
        CL = Cells(2 + PlanID, 11) 'cycle length
        Offset = Cells(2 + PlanID, 12)
        CLVSheet. Cells(2 + Planrow, 15) = ICode
        CLVSheet. Cells(2 + Planrow, 16) = Phase2
```

```
        CLVSheet. Cells(2 + Planrow, 17) = Phase1
        CLVSheet. Cells(2 + Planrow, 18) = Phase6
        CLVSheet. Cells(2 + Planrow, 19) = Phase8
        CLVSheet. Cells(2 + Planrow, 24) = CL
        CLVSheet. Cells(2 + Planrow, 25) = Offset

    ElseIf IntID = 6 Then 'SB intersection
        Phase2 = Cells(2 + PlanID, 4) 'NBT2
        Phase4 = Cells(2 + PlanID, 6) 'WBL2
        Phase5 = Cells(2 + PlanID, 7) 'NBL2
        Phase6 = Cells(2 + PlanID, 8) ' SBT2
        Offset = Cells(2 + PlanID, 12)
        CLVSheet. Cells(2 + Planrow, 20) = Phase2
        CLVSheet. Cells(2 + Planrow, 21) = Phase4
        CLVSheet. Cells(2 + Planrow, 22) = Phase5
        CLVSheet. Cells(2 + Planrow, 23) = Phase6
        CLVSheet. Cells(2 + Planrow, 26) = Offset
        Planrow = Planrow + 1 'add 1 to Planrow if IntID = 6

    End If

Next PlanID

End Sub
```

A.2 Volume-to-Capacity Ratio Calculation and Redistribution

Following VB scripts automatically inputs traffic demands and turn movement ratios into the “DDI_CLV” and “CDI_CLV” worksheets in the CLV workbook and relocate calculated v/c ratios to “Color Coded” worksheet, where calculated DDI and CDI v/c ratios are color-coded and plotted for the comparison.

A.2.1 DDI_CLV script

```
Sub CLVTableFillDDI()

Dim JCEnterVol As Integer
Dim I85OffVol As Integer
For VolumeCase = 1 To 7
    JCEnterVol = Cells(3 + VolumeCase, 30)

    For RampCase = 1 To 4
        I85OffVol = Cells(3 + VolumeCase, 30 + RampCase)

        If I85OffVol >= 1 Then

            For PropLeft = 1 To 7
                Prop = Cells(3 + PropLeft, 37)
```

```
                Cells(3, 2) = JCEnterVol
                Cells(4, 2) = I85OffVol
                Cells(5, 7) = Prop
                VCNBT1 = Cells(56, 3)
                VCSBT1 = Cells(57, 3)
                VCSBL1 = Cells(58, 3)
                VCEBL1 = Cells(59, 3)
                VCNBT2 = Cells(54, 6)
                VCNBL2 = Cells(55, 6)
                VCSBT2 = Cells(58, 6)
                VCWBL2 = Cells(59, 6)
                Intvc = Cells(59, 10)
                Sheets("Color Coded"). Cells(7 + PropLeft, 2 + (((VolumeCase - 1) *
11) + (RampCase * 2))) = VCNBT1
                Sheets("Color Coded"). Cells(14 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBT1
                Sheets("Color Coded"). Cells(21 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBL1
                Sheets("Color Coded"). Cells(28 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCEBL1
                Sheets("Color Coded"). Cells(35 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCNBT2
                Sheets("Color Coded"). Cells(42 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCNBL2
                Sheets("Color Coded"). Cells(49 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBT2
                Sheets("Color Coded"). Cells(56 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCWBL2
                Sheets("Color Coded"). Cells(63 + PropLeft, 2 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = Intvc

           Next PropLeft

        End If

    Next RampCase

Next VolumeCase

End Sub
```

A.2.2 CDI_CLV script

```
Sub CLVTableFillCDI()

Dim JCEnterVol As Integer
Dim I85OffVol As Integer

For VolumeCase = 1 To 7
    JCEnterVol = Cells(3 + VolumeCase, 30)

    For RampCase = 1 To 4
        I85OffVol = Cells(3 + VolumeCase, 30 + RampCase)

        If I85OffVol >= 1 Then
```

```
            For PropLeft = 1 To 7 'Can be up to 7
                Prop = Cells(3 + PropLeft, 37)
                'Enter Volumes to be test into calculator
                Cells(3, 2) = JCEnterVol
                Cells(4, 2) = I85OffVol
                Cells(5, 7) = Prop
                VCNBT1 = Cells(56, 3)
                VCSBT1 = Cells(57, 3)
                VCSBL1 = Cells(58, 3)
                VCEBL1 = Cells(59, 3)
                VCNBT2 = Cells(54, 6)
                VCNBL2 = Cells(55, 6)
                VCSBT2 = Cells(58, 6)
                VCWBL2 = Cells(59, 6)
                Intvc = Cells(59, 10)
                Sheets("Color Coded"). Cells(7 + PropLeft, 1 + (((VolumeCase - 1) *
11) + (RampCase * 2))) = VCNBT1
                Sheets("Color Coded"). Cells(14 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBT1
                Sheets("Color Coded"). Cells(21 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBL1
                Sheets("Color Coded"). Cells(28 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCEBL1
                Sheets("Color Coded"). Cells(35 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCNBT2
                Sheets("Color Coded"). Cells(42 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCNBL2
                Sheets("Color Coded"). Cells(49 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCSBT2
                Sheets("Color Coded"). Cells(56 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = VCWBL2
                Sheets("Color Coded"). Cells(63 + PropLeft, 1 + (((VolumeCase - 1)
* 11) + (RampCase * 2))) = Intvc

             Next PropLeft

        End If

    Next RampCase

Next VolumeCase

End Sub
```

APPENDIX C. MICROSOFT VISUAL STUDIO VISUAL BASIC SCRIPTS

This appendix provides the VB script in Microsoft Visual Studio, which automates the procedure for inputting and assigning variables, collecting and relocating output files from the VISSIM simulation study. This script allows user to collect necessary output files from the VISSIM simulation with varying traffic scenarios and lane configurations without having to manually open and run individual input files.

```
'Imports System. Text'
Imports System. Convert
Imports System. Math
Imports System
Imports System. IO
Imports System. Threading

Imports VISSIM_COMSERVERLib
Module Module1
    Dim vissim As Vissim
    Dim net As Net
    Dim simulation As Simulation
    Dim vehicles As Vehicles
    Dim vehicle As Vehicle
    Dim links As Links
    Dim link As Link
    Dim evaluation As Evaluation
    Dim vehinps As VehicleInputs
    Dim decisions As RoutingDecisions
    Dim decision As RoutingDecision
    Dim JC As Integer
    Dim Off As Integer
    Dim m As Integer
    Dim simtime = 4500
    Dim resolution = 10
    Sub Main()
        'set groups of arrays that contain vehicle inputs
        Dim vehinp1() As Integer = New Integer() {1500, 2100, 2500} 'Jimmy Carter
NB1
        Dim vehinp2() As Integer = New Integer() {1500, 2100, 2500} 'Jimmy Carter
SB2
        Dim vehinp3() As Integer = New Integer() {500, 1100, 1800} 'I-85 off-ramp
NB
        Dim vehinp4() As Integer = New Integer() {500, 1100, 1800} 'I-85 off-ramp
SB

        'set groups of arrays that contain different route decisions
```

```
        Dim decision1_1() As Double = New Double() {0. 8, 0. 72, 0. 56, 0. 4, 0.
24, 0. 08, 0} 'NBT2
        Dim decision1_2() As Double = New Double() {0, 0. 08, 0. 24, 0. 4, 0. 56,
0. 72, 0. 8} 'NBL2
        Dim decision1_3() As Double = New Double() {0. 2} 'NBR1
        Dim decision2_1() As Double = New Double() {0. 8, 0. 72, 0. 56, 0. 4, 0.
24, 0. 08, 0} 'SBT1
        Dim decision2_2() As Double = New Double() {0, 0. 08, 0. 24, 0. 4, 0. 56,
0. 72, 0. 8} 'SBL1
        Dim decision2_3() As Double = New Double() {0. 2} 'SBR2
        Dim decision3_1() As Double = New Double() {0. 5} 'EBL1
        Dim decision3_2() As Double = New Double() {0. 5} 'EBR1
        Dim decision4_1() As Double = New Double() {0. 5} 'WBL2
        Dim decision4_2() As Double = New Double() {0. 5} 'WBR2

        For l As Integer = 1 To 3 'For loop for lane configuration

            'For-loop to insert desired routing decision into the model
            JC = 0 'counter for Jimmy Carter volumes

            'For-loop to run through different traffic volumes and turn movement
ratios
            For i As Integer = 1 To 3 'For loop for JC volumes (1: 1500, 2: 2100,
3: 2500)

                Off = 0 'counter for Off-ramp volumes

                For j As Integer = 1 To 3 'For loop for Off-ramp volumes (1: 500,
2: 1100, 3: 1800)

                    m = 0 'counter for route decisions

                    For k As Integer = 1 To 7 '7 different turning movement
proportions (1: 100/0, 2: 90/10, 3: 70/30, 4: 50/50, 5: 30/70, 6: 10/90, 7: 0:100)

                        For n As Integer = 1 To 2

                            'Initializing a new instance of Vissim'
                            vissim = New Vissim

                            If n = 1 Then 'running DDI models
                                'loading Vissim network model ". inp" file and ".
ini" file for offset test
                                'this is to call DDI files
                                vissim. LoadNet("C:\Users\spark365\Documents\Sung
Jun Park\Research\DDI\After\DDI Final\VISSIM\LC" & l & "\After\" & i & "_" & j &
"\DDI_PM_" & k & ". inp")
                                vissim.
LoadLayout("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\vissim. ini")

                                'you may minimize the VISSIM window if you want'
                                vissim. ShowMinimized()

                                'initiate route decision and vehicle input
variable
                                Dim vehinps = vissim. Net. VehicleInputs
                                Dim decisions = vissim. Net. RoutingDecisions
```

```
                                'initiate vehicle nput for each approach
                                Dim vehinpNB = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(26) 'number in the bracket is link/connector number in
VISSIM
                                Dim vehinpSB = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(1)
                                Dim vehinpNBRamp = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(10)
                                Dim vehinpSBRamp = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(24)

                                'initiate route decisions for each approach
                                Dim decisionNB = decisions.
GetRoutingDecisionByNumber(1) 'number in the bracket is route decision number in
VISSIM
                                Dim decisionSB = decisions.
GetRoutingDecisionByNumber(2)
                                Dim decisionNBR = decisions.
GetRoutingDecisionByNumber(3)
                                Dim decisionSBR = decisions.
GetRoutingDecisionByNumber(4)

                                'add vehicle input from desired vehicle input
group for each time frame
                                vehinpNB = vehinps. AddVehicleInput(26, 0, 4500)
'vehinps. AddVehincleInput(link/connector #, start time, end time)
                                vehinpNB. AttValue("Volume") = vehinp1(JC) 'this
calls the first number from the array of vehinp1 (the first number in the array is
0th position)
                                vehinpNB. AttValue("TrafficComposition") = 1 '1
for Default, 2 for DDI (currently no difference between the two)

                                vehinpSB = vehinps. AddVehicleInput(1, 0, 4500)
                                vehinpSB. AttValue("Volume") = vehinp2(JC)
                                vehinpSB. AttValue("TrafficComposition") = 1

                                vehinpNBRamp = vehinps. AddVehicleInput(10, 0,
4500)
                                vehinpNBRamp. AttValue("Volume") = vehinp3(Off)
                                vehinpNBRamp. AttValue("TrafficComposition") = 1

                                vehinpSBRamp = vehinps. AddVehicleInput(24, 0,
4500)
                                vehinpSBRamp. AttValue("Volume") = vehinp4(Off)
                                vehinpSBRamp. AttValue("TrafficComposition") = 1

                                'add route decision from desired route decision
group for each time frame
                                'DDI NB:
                                decisionNB. AttValue2("RelativeFlow", 1, 4500) =
decision1_1(m) 'decisionX. AttValue2("RelativeFlow, Decision #, end time) =
decision1_X(position of proportion that you want to call)
                                decisionNB. AttValue2("RelativeFlow", 2, 4500) =
decision1_2(m)
                                decisionNB. AttValue2("RelativeFlow", 3, 4500) =
decision1_3(0)
                                'DDI SB:
```

```
                                decisionSB. AttValue2("RelativeFlow", 1, 4500) =
decision2_1(m)
                                decisionSB. AttValue2("RelativeFlow", 2, 4500) =
decision2_2(m)
                                decisionSB. AttValue2("RelativeFlow", 3, 4500) =
decision2_3(0)
                                'NB Ramp:
                                decisionNBR. AttValue2("RelativeFlow", 1, 4500) =
decision3_1(0)
                                decisionNBR. AttValue2("RelativeFlow", 2, 4500) =
decision3_2(0)
                                'SB Ramp:
                                decisionSBR. AttValue2("RelativeFlow", 1, 4500) =
decision4_1(0)
                                decisionSBR. AttValue2("RelativeFlow", 2, 4500) =
decision4_2(0)

                                Dim randseed = 1 'this allows you to change random
seed in VISSIM in each run, and thus you get some variable flows in each run

                                For randcount = 1 To 10 'number of runs for a
particular traffic volume and route decision combinations with different seeds in
each run

                                    'activating evaluation tools in the file'
                                    evaluation = vissim. Evaluation
                                    evaluation. AttValue("traveltime") = True
                                    evaluation. AttValue("delay") = True
                                    evaluation. AttValue("datacollection") = True
                                    evaluation. AttValue("queuecounter") = True
                                    evaluation. AttValue("vehiclerecord") = True

                                    'assigning simulation propoerties'
                                    simulation = vissim. Simulation
                                    simulation. Period = simtime
                                    simulation. Resolution = resolution
                                    simulation. RandomSeed = randseed
                                    simulation. RunContinuous()

                                    Thread. Sleep(5000)

                                    'rename and move output files into separate
folder
                                    'relocate output file - Data Collection Raw(.
mer), Data Collection Compiled(. mes), Delay Raw(. vlr), Delay Compiled(. vlz),
Travel Time Raw(. rsr), Travel Time Compiled(. rsz), and Error files(. err)'
                                    'for DDI model
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". mer",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\dc\raw\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". mes",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
```

```
l & "\After\dc\comp\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". vlr",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\delay\raw\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". vlz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\delay\comp\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". rsr",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\tt\raw\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". rsz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\tt\comp\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". stz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\queue\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount &
". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\After\" & i & "_" & j & "\DDI_PM_" & k & ". fzp",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\After\vr\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount & ".
txt", True)

                                    randseed = randseed + 11 'add 11 to random
seed after each run

                                Next
                                vissim. Exit() 'exit currently opened VISSIM file

                            ElseIf n = 2 Then 'running CDI models
                                'this is to call CDI files
                                vissim. LoadNet("C:\Users\spark365\Documents\Sung
Jun Park\Research\DDI\After\DDI Final\VISSIM\LC" & l & "\Before\" & i & "_" & j &
"\Before_PM_" & k & ". inp")
                                vissim.
LoadLayout("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\vissim. ini")

                                'you may minimize the VISSIM window if you want'
                                vissim. ShowMinimized()
```

```
                                'initiate route decision and vehicle input
variable
                                Dim vehinps = vissim. Net. VehicleInputs
                                Dim decisions = vissim. Net. RoutingDecisions

                                'initiate vehicle nput for each approach
                                Dim vehinpNB = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(26) 'number in the bracket is link/connector number in
VISSIM
                                Dim vehinpSB = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(1)
                                Dim vehinpNBRamp = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(10)
                                Dim vehinpSBRamp = vissim. Net. VehicleInputs.
GetVehicleInputByNumber(24)

                                'initiate route decisions for each approach
                                Dim decisionNB = decisions.
GetRoutingDecisionByNumber(1) 'number in the bracket is route decision number in
VISSIM
                                Dim decisionSB = decisions.
GetRoutingDecisionByNumber(2)
                                Dim decisionNBR = decisions.
GetRoutingDecisionByNumber(3)
                                Dim decisionSBR = decisions.
GetRoutingDecisionByNumber(4)

                                'add vehicle input from desired vehicle input
group for each time frame
                                vehinpNB = vehinps. AddVehicleInput(26, 0, 4500)
'vehinps. AddVehincleInput(link/connector #, start time, end time)
                                vehinpNB. AttValue("Volume") = vehinp1(JC) 'this
calls the first number from the array of vehinp1 (the first number in the array is
0th position)
                                vehinpNB. AttValue("TrafficComposition") = 1 '1
for Default, 2 for DDI (currently no difference between the two)

                                vehinpSB = vehinps. AddVehicleInput(1, 0, 4500)
                                vehinpSB. AttValue("Volume") = vehinp2(JC)
                                vehinpSB. AttValue("TrafficComposition") = 1

                                vehinpNBRamp = vehinps. AddVehicleInput(10, 0,
4500)
                                vehinpNBRamp. AttValue("Volume") = vehinp3(Off)
                                vehinpNBRamp. AttValue("TrafficComposition") = 1

                                vehinpSBRamp = vehinps. AddVehicleInput(24, 0,
4500)
                                vehinpSBRamp. AttValue("Volume") = vehinp4(Off)
                                vehinpSBRamp. AttValue("TrafficComposition") = 1

                                'add route decision from desired route decision
group for each time frame
                                'DDI NB:
                                decisionNB. AttValue2("RelativeFlow", 1, 4500) =
decision1_1(m) 'decisionX. AttValue2("RelativeFlow, Decision #, end time) =
decision1_X(position of proportion that you want to call)
```

```
                                decisionNB. AttValue2("RelativeFlow", 2, 4500) =
decision1_2(m)
                                decisionNB. AttValue2("RelativeFlow", 3, 4500) =
decision1_3(0)
                                'DDI SB:
                                decisionSB. AttValue2("RelativeFlow", 1, 4500) =
decision2_1(m)
                                decisionSB. AttValue2("RelativeFlow", 2, 4500) =
decision2_2(m)
                                decisionSB. AttValue2("RelativeFlow", 3, 4500) =
decision2_3(0)
                                'NB Ramp:
                                decisionNBR. AttValue2("RelativeFlow", 1, 4500) =
decision3_1(0)
                                decisionNBR. AttValue2("RelativeFlow", 2, 4500) =
decision3_2(0)
                                'SB Ramp:
                                decisionSBR. AttValue2("RelativeFlow", 1, 4500) =
decision4_1(0)
                                decisionSBR. AttValue2("RelativeFlow", 2, 4500) =
decision4_2(0)

                                Dim randseed = 1 'this allows you to change random
seed in VISSIM in each run, and thus you get some variable flows in each run

                                For randcount = 1 To 10 'number of runs for a
particular traffic volume and route decision combinations with different seeds in
each run

                                    'activating evaluation tools in the file'
                                    evaluation = vissim. Evaluation
                                    evaluation. AttValue("traveltime") = True
                                    evaluation. AttValue("delay") = True
                                    evaluation. AttValue("datacollection") = True
                                    evaluation. AttValue("queuecounter") = True
                                    evaluation. AttValue("vehiclerecord") = True

                                    'assigning simulation propoerties'
                                    simulation = vissim. Simulation
                                    simulation. Period = simtime
                                    simulation. Resolution = resolution
                                    simulation. RandomSeed = randseed
                                    simulation. RunContinuous()

                                    Thread. Sleep(5000)

                                    'rename and move output files into separate
folder
                                    'relocate output file - Data Collection Raw(.
mer), Data Collection Compiled(. mes), Delay Raw(. vlr), Delay Compiled(. vlz),
Travel Time Raw(. rsr), Travel Time Compiled(. rsz), and Error files(. err)'
                                    'for CDI model
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". mer",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\dc\raw\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
```

```
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". mes",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\dc\comp\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". vlr",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\delay\raw\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". vlz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\delay\comp\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". rsr",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\tt\raw\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". rsz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\tt\comp\volume" & i & "_" & j & "\proportion" & k & "\run" &
randcount & ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". stz",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\queue\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount
& ". txt", True)
                                    My. Computer. FileSystem.
CopyFile("C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI
Final\VISSIM\LC" & l & "\Before\" & i & "_" & j & "\Before_PM_" & k & ". fzp",
"C:\Users\spark365\Documents\Sung Jun Park\Research\DDI\After\DDI Final\Data\LC" &
l & "\Before\vr\volume" & i & "_" & j & "\proportion" & k & "\run" & randcount &
". txt", True)

                                    randseed = randseed + 11 'add 11 to random
seed after each run

                                Next
                                vissim. Exit() 'exit currently opened VISSIM file

                            End If

                        Next
                        m = m + 1 'add 1 to move to next routing proportion

                    Next
                    Off = Off + 1 'add 1 to move to next off-ramp volume

                Next
```

```
                JC = JC + 1 'add 1 to move to next JC volume
            Next
        Next
    End Sub

End Module
```

APPENDIX D. CRITICAL LANE VOLUME ANALYSIS RESULTS

This appendix provides resulted color-coded tables and plots showing the difference in the CDI and DDI v/c ratios at different through/left proportions, traffic demands, and lane configurations.

D.1 Lane Configuration 1

D.1.1 Color-Coded Tables of CDI and DDI v/c ratios

The following color-coded tables show comparison of the CDI and DDI v/c ratios calculated using the CLV method for LC1. The color schematic of these tables are described in Table 6.

Table D-1: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1000 vph (b) cross street demand of 1500 vph with different off-ramp demands and through/left proportions for LC1

(a)

JC Volume 1000 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		200 vph		500 vph		800 vph	
100:0	NBT1	0.28	0.56	0.33	0.60	0.34	0.63
90:10		0.50	0.49	0.51	0.54	0.56	0.57
70:30		0.50	0.35	0.50	0.39	0.54	0.41
50:50		0.37	0.32	0.41	0.35	0.43	0.37
30:70		0.65	0.30	0.60	0.33	0.70	0.37
10:90		0.84	0.36	0.90	0.39	1.05	0.43
0:100		1.00	0.38	1.07	0.42	1.07	0.45
100:0	SBT1	0.32	0.44	0.44	0.51	0.52	0.56
90:10		0.31	0.42	0.39	0.47	0.48	0.53
70:30		0.24	0.37	0.31	0.44	0.39	0.50
50:50		0.16	0.31	0.23	0.37	0.30	0.43
30:70		0.11	0.24	0.17	0.31	0.23	0.36
10:90		0.06	0.14	0.11	0.23	0.17	0.30
0:100		0.03	0.08	0.08	0.18	0.13	0.26
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.18	0.02	0.20	0.02	0.22	0.02
70:30		0.35	0.06	0.40	0.06	0.43	0.06
50:50		0.45	0.10	0.48	0.10	0.55	0.10
30:70		0.58	0.14	0.65	0.14	0.63	0.14
10:90		0.55	0.18	0.53	0.18	0.53	0.18
0:100		0.52	0.20	0.50	0.20	0.49	0.20
100:0	EBL1	0.13	0.05	0.26	0.12	0.38	0.19
90:10		0.14	0.05	0.25	0.12	0.38	0.19
70:30		0.18	0.06	0.35	0.14	0.45	0.21
50:50		0.22	0.06	0.36	0.14	0.50	0.22
30:70		0.25	0.07	0.47	0.16	0.54	0.23
10:90		0.35	0.08	0.55	0.17	0.58	0.25
0:100		0.33	0.08	0.56	0.18	0.67	0.26
100:0	NBT2	0.32	0.43	0.44	0.49	0.52	0.55
90:10		0.31	0.41	0.39	0.47	0.48	0.51
70:30		0.24	0.35	0.32	0.42	0.40	0.48
50:50		0.17	0.30	0.24	0.35	0.32	0.42
30:70		0.11	0.22	0.18	0.29	0.24	0.35
10:90		0.06	0.13	0.12	0.22	0.18	0.29
0:100		0.03	0.08	0.08	0.17	0.15	0.24
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.13	0.02	0.13	0.02	0.17	0.02
70:30		0.25	0.06	0.27	0.06	0.30	0.06
50:50		0.32	0.10	0.35	0.10	0.40	0.10
30:70		0.40	0.14	0.42	0.14	0.45	0.14
10:90		0.45	0.18	0.48	0.18	0.48	0.18
0:100		0.43	0.20	0.45	0.20	0.48	0.20
100:0	SBT2	0.28	0.58	0.33	0.63	0.34	0.67
90:10		0.43	0.51	0.45	0.54	0.47	0.60
70:30		0.37	0.37	0.41	0.41	0.44	0.44
50:50		0.54	0.33	0.58	0.37	0.67	0.39
30:70		0.84	0.32	0.99	0.35	0.98	0.39
10:90		1.15	0.38	1.26	0.41	1.33	0.45
0:100		1.28	0.40	1.39	0.43	1.52	0.50
100:0	WBL2	0.13	0.05	0.26	0.12	0.38	0.18
90:10		0.14	0.05	0.25	0.12	0.38	0.18
70:30		0.18	0.05	0.31	0.13	0.42	0.20
50:50		0.18	0.06	0.31	0.16	0.40	0.21
30:70		0.21	0.07	0.34	0.15	0.44	0.22
10:90		0.22	0.07	0.36	0.14	0.47	0.24
0:100		0.25	0.08	0.38	0.17	0.47	0.24
100:0	Int v/c	0.28	0.48	0.39	0.53	0.48	0.58
90:10		0.32	0.44	0.35	0.49	0.45	0.53
70:30		0.38	0.35	0.42	0.41	0.47	0.45
50:50		0.39	0.31	0.44	0.35	0.50	0.40
30:70		0.56	0.27	0.60	0.31	0.63	0.36
10:90		0.68	0.27	0.73	0.31	0.75	0.36
0:100		0.72	0.27	0.75	0.31	0.80	0.36

(b)

JC Volume 1500 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.44	0.88	0.47	0.97	0.48	1.06
90:10		0.70	0.76	0.77	0.84	0.68	0.92
70:30		0.70	0.54	0.74	0.62	0.80	0.66
50:50		0.55	0.48	0.62	0.55	0.68	0.64
30:70		0.90	0.48	0.95	0.55	1.05	0.57
10:90		1.25	0.56	1.35	0.64	1.48	0.70
0:100		1.50	0.60	1.60	0.68	1.76	0.72
100:0	SBT1	0.53	0.69	0.69	0.70	0.83	0.75
90:10		0.50	0.65	0.66	0.66	0.81	0.78
70:30		0.39	0.56	0.55	0.63	0.76	0.69
50:50		0.28	0.49	0.42	0.59	0.60	0.67
30:70		0.19	0.40	0.31	0.52	0.47	0.63
10:90		0.11	0.27	0.21	0.42	0.35	0.55
0:100		0.07	0.20	0.17	0.36	0.31	0.49
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.28	0.03	0.30	0.03	0.36	0.03
70:30		0.56	0.09	0.64	0.09	0.69	0.09
50:50		0.70	0.15	0.78	0.15	0.81	0.15
30:70		0.65	0.21	0.63	0.21	0.61	0.21
10:90		0.53	0.27	0.51	0.27	0.51	0.27
0:100		0.49	0.30	0.48	0.30	0.45	0.30
100:0	EBL1	0.34	0.12	0.59	0.23	0.78	0.35
90:10		0.31	0.12	0.55	0.22	0.75	0.35
70:30		0.45	0.13	0.59	0.25	0.69	0.36
50:50		0.49	0.14	0.69	0.28	0.78	0.40
30:70		0.56	0.16	0.76	0.31	0.88	0.45
10:90		0.74	0.18	0.88	0.34	0.98	0.48
0:100		0.74	0.20	0.92	0.36	1.03	0.49
100:0	NBT2	0.53	0.67	0.69	0.72	0.83	0.75
90:10		0.50	0.63	0.66	0.66	0.81	0.76
70:30		0.40	0.55	0.56	0.63	0.76	0.68
50:50		0.29	0.47	0.44	0.58	0.64	0.67
30:70		0.20	0.38	0.33	0.52	0.51	0.60
10:90		0.11	0.26	0.23	0.40	0.39	0.53
0:100		0.08	0.18	0.18	0.34	0.31	0.45
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.20	0.03	0.23	0.03	0.27	0.03
70:30		0.41	0.09	0.45	0.09	0.51	0.09
50:50		0.50	0.15	0.58	0.15	0.63	0.15
30:70		0.57	0.21	0.64	0.21	0.63	0.21
10:90		0.47	0.27	0.48	0.27	0.48	0.27
0:100		0.41	0.30	0.42	0.30	0.42	0.30
100:0	SBT2	0.44	0.91	0.47	1.00	0.48	1.13
90:10		0.60	0.79	0.65	0.84	0.59	0.98
70:30		0.55	0.57	0.60	0.62	0.60	0.69
50:50		0.81	0.50	0.88	0.57	0.97	0.64
30:70		1.18	0.50	1.31	0.55	1.49	0.61
10:90		1.60	0.59	1.80	0.68	1.95	0.74
0:100		1.86	0.63	2.04	0.71	2.32	0.81
100:0	WBL2	0.34	0.12	0.59	0.23	0.78	0.34
90:10		0.31	0.12	0.55	0.22	0.75	0.34
70:30		0.39	0.13	0.55	0.25	0.69	0.35
50:50		0.40	0.14	0.60	0.28	0.68	0.40
30:70		0.43	0.16	0.60	0.31	0.73	0.43
10:90		0.48	0.17	0.64	0.33	0.77	0.47
0:100		0.51	0.18	0.67	0.34	0.78	0.45
100:0	Int v/c	0.49	0.75	0.66	0.80	0.82	0.85
90:10		0.46	0.68	0.63	0.72	0.79	0.82
70:30		0.60	0.54	0.66	0.62	0.73	0.68
50:50		0.62	0.48	0.71	0.56	0.77	0.65
30:70		0.80	0.43	0.87	0.52	0.94	0.59
10:90		0.89	0.43	0.95	0.52	1.01	0.61
0:100		0.94	0.43	0.99	0.52	1.06	0.59

Table D-2: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1800 vph (b) cross street demand of 2100 vph with different off-ramp demands and through/left proportions for LC1

(a)

Proportion	Approach	JC Volume 1800 vph					
		CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0		0.51	1.03	0.52	1.11	0.54	1.25
90:10		0.85	0.91	0.84	0.97	0.77	1.08
70:30		0.76	0.63	0.84	0.70	0.91	0.78
50:50	NBT1	0.65	0.56	0.68	0.62	0.76	0.70
30:70		0.99	0.54	1.08	0.60	1.17	0.67
10:90		1.47	0.65	1.62	0.72	1.72	0.78
0:100		1.75	0.69	1.87	0.77	2.03	0.84
100:0		0.60	0.67	0.72	0.72	0.87	0.75
90:10		0.57	0.71	0.70	0.78	0.86	0.78
70:30		0.43	0.63	0.58	0.71	0.78	0.80
50:50	SBT1	0.30	0.55	0.43	0.62	0.61	0.73
30:70		0.20	0.44	0.31	0.57	0.47	0.65
10:90		0.11	0.31	0.22	0.43	0.35	0.57
0:100		0.07	0.21	0.17	0.36	0.29	0.51
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.31	0.04	0.34	0.04	0.40	0.04
70:30		0.65	0.11	0.69	0.11	0.75	0.11
50:50	SBL1	0.75	0.18	0.85	0.18	0.82	0.18
30:70		0.64	0.25	0.64	0.25	0.64	0.25
10:90		0.54	0.32	0.52	0.32	0.52	0.32
0:100		0.49	0.36	0.48	0.36	0.48	0.36
100:0		0.38	0.11	0.65	0.23	0.84	0.34
90:10		0.34	0.11	0.60	0.24	0.80	0.35
70:30		0.47	0.13	0.64	0.25	0.75	0.38
50:50	EBL1	0.56	0.14	0.77	0.27	0.85	0.41
30:70		0.74	0.16	0.86	0.32	1.01	0.44
10:90		0.85	0.20	0.98	0.34	1.13	0.49
0:100		0.91	0.21	1.07	0.36	1.19	0.51
100:0		0.60	0.68	0.72	0.72	0.87	0.75
90:10		0.57	0.71	0.70	0.80	0.86	0.78
70:30		0.44	0.62	0.59	0.70	0.78	0.78
50:50	NBT2	0.31	0.53	0.45	0.62	0.65	0.73
30:70		0.21	0.43	0.33	0.55	0.48	0.63
10:90		0.12	0.29	0.23	0.42	0.33	0.54
0:100		0.07	0.20	0.16	0.34	0.25	0.48
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.24	0.04	0.25	0.04	0.30	0.04
70:30		0.46	0.11	0.54	0.11	0.61	0.11
50:50	NBL2	0.56	0.18	0.65	0.18	0.71	0.18
30:70		0.63	0.25	0.62	0.25	0.65	0.25
10:90		0.45	0.32	0.46	0.32	0.48	0.32
0:100		0.40	0.36	0.42	0.36	0.42	0.36
100:0		0.51	1.05	0.52	1.14	0.54	1.27
90:10		0.69	0.91	0.71	1.01	0.68	1.10
70:30		0.60	0.65	0.63	0.72	0.65	0.80
50:50	SBT2	0.88	0.58	0.95	0.62	1.07	0.70
30:70		1.31	0.56	1.43	0.63	1.60	0.70
10:90		1.83	0.68	2.03	0.75	2.20	0.84
0:100		2.13	0.72	2.40	0.80	2.54	0.90
100:0		0.38	0.11	0.65	0.22	0.84	0.34
90:10		0.34	0.11	0.60	0.24	0.80	0.35
70:30		0.42	0.12	0.60	0.25	0.75	0.37
50:50	WBL2	0.47	0.14	0.65	0.27	0.75	0.41
30:70		0.51	0.16	0.67	0.31	0.81	0.43
10:90		0.59	0.18	0.74	0.33	0.87	0.46
0:100		0.63	0.20	0.77	0.34	0.90	0.48
100:0		0.56	0.81	0.71	0.86	0.86	0.90
90:10		0.57	0.78	0.68	0.86	0.84	0.88
70:30		0.66	0.62	0.73	0.70	0.77	0.78
50:50	Int v/c	0.70	0.54	0.78	0.61	0.86	0.71
30:70		0.90	0.49	0.94	0.57	1.03	0.65
10:90		1.00	0.50	1.06	0.57	1.13	0.66
0:100		1.06	0.50	1.14	0.57	1.19	0.66

(b)

Proportion	Approach	JC Volume 2100 vph					
		CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0		0.57	1.20	0.58	1.26	0.60	1.37
90:10		0.95	1.01	0.85	1.09	0.81	1.19
70:30		0.84	0.72	0.91	0.80	0.98	0.87
50:50	NBT1	0.72	0.63	0.75	0.70	0.81	0.76
30:70		1.15	0.61	1.25	0.69	1.32	0.74
10:90		1.72	0.73	1.84	0.81	2.00	0.86
0:100		2.04	0.78	2.22	0.84	2.36	0.93
100:0		0.65	0.67	0.77	0.73	0.92	0.79
90:10		0.65	0.75	0.75	0.77	0.89	0.82
70:30		0.46	0.69	0.61	0.77	0.80	0.85
50:50	SBT1	0.33	0.60	0.45	0.71	0.61	0.78
30:70		0.22	0.49	0.33	0.60	0.47	0.68
10:90		0.12	0.35	0.22	0.47	0.35	0.59
0:100		0.07	0.22	0.16	0.39	0.29	0.51
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.42	0.04	0.45	0.04	0.45	0.04
70:30		0.67	0.13	0.73	0.13	0.82	0.13
50:50	SBL1	0.84	0.21	0.82	0.21	0.81	0.21
30:70		0.64	0.29	0.65	0.29	0.63	0.29
10:90		0.55	0.38	0.52	0.38	0.51	0.38
0:100		0.49	0.42	0.49	0.42	0.47	0.42
100:0		0.44	0.11	0.69	0.22	0.88	0.35
90:10		0.39	0.11	0.69	0.23	0.84	0.36
70:30		0.50	0.12	0.69	0.24	0.80	0.37
50:50	EBL1	0.63	0.14	0.83	0.28	0.93	0.40
30:70		0.83	0.16	0.96	0.31	1.09	0.43
10:90		0.94	0.21	1.13	0.36	1.23	0.50
0:100		1.02	0.22	1.18	0.39	1.31	0.51
100:0		0.65	0.67	0.77	0.73	0.92	0.79
90:10		0.65	0.75	0.77	0.77	0.89	0.82
70:30		0.47	0.68	0.63	0.76	0.82	0.84
50:50	NBT2	0.34	0.60	0.47	0.70	0.65	0.77
30:70		0.22	0.47	0.34	0.60	0.46	0.67
10:90		0.12	0.33	0.20	0.45	0.30	0.58
0:100		0.07	0.21	0.14	0.38	0.22	0.51
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.30	0.04	0.37	0.04	0.39	0.04
70:30		0.50	0.13	0.60	0.13	0.66	0.13
50:50	NBL2	0.62	0.21	0.68	0.21	0.76	0.21
30:70		0.58	0.29	0.60	0.29	0.62	0.29
10:90		0.45	0.38	0.45	0.38	0.45	0.38
0:100		0.39	0.42	0.39	0.42	0.41	0.42
100:0		0.57	1.20	0.58	1.28	0.60	1.40
90:10		0.82	1.03	0.76	1.11	0.69	1.22
70:30		0.64	0.74	0.68	0.81	0.72	0.88
50:50	SBT2	0.96	0.63	1.03	0.72	1.15	0.78
30:70		1.47	0.62	1.61	0.69	1.76	0.75
10:90		2.06	0.76	2.27	0.84	2.52	0.89
0:100		2.44	0.81	2.61	0.87	2.91	0.93
100:0		0.44	0.11	0.69	0.22	0.88	0.35
90:10		0.39	0.11	0.64	0.23	0.84	0.35
70:30		0.45	0.12	0.62	0.24	0.77	0.36
50:50	WBL2	0.53	0.14	0.67	0.28	0.78	0.40
30:70		0.59	0.16	0.77	0.31	0.86	0.43
10:90		0.72	0.20	0.83	0.34	0.94	0.49
0:100		0.70	0.21	0.88	0.38	0.99	0.51
100:0		0.62	0.86	0.75	0.91	0.91	0.98
90:10		0.69	0.85	0.74	0.89	0.87	0.95
70:30		0.72	0.70	0.79	0.77	0.87	0.85
50:50	Int v/c	0.78	0.61	0.83	0.70	0.92	0.77
30:70		0.97	0.54	1.04	0.63	1.10	0.70
10:90		1.12	0.57	1.17	0.64	1.24	0.72
0:100		1.18	0.57	1.24	0.64	1.32	0.72

Table D-3: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2300 vph with different off-ramp demands and through/left proportions for LC1

		JC Volume 2300 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0		0.59	1.27	0.62	1.38	0.65	1.24	0.67	1.56
90:10		0.88	1.10	0.86	1.18	0.87	0.99	0.89	1.35
70:30		0.89	0.78	0.95	0.84	1.04	0.93	1.03	0.97
50:50	NBT1	0.75	0.67	0.81	0.75	0.88	0.84	0.91	0.84
30:70		1.24	0.66	1.35	0.71	1.45	0.79	1.49	0.82
10:90		1.86	0.78	2.01	0.83	2.13	0.91	2.18	0.95
0:100		2.18	0.82	2.30	0.89	2.51	0.96	2.44	1.01
100:0		0.67	0.68	0.81	0.73	0.96	0.88	1.05	0.82
90:10		0.64	0.73	0.76	0.77	0.92	0.98	1.00	0.85
70:30		0.49	0.75	0.63	0.81	0.83	0.90	0.90	0.95
50:50	SBT1	0.34	0.63	0.47	0.74	0.63	0.78	0.70	0.85
30:70		0.23	0.52	0.34	0.62	0.48	0.73	0.54	0.75
10:90		0.12	0.34	0.22	0.49	0.33	0.61	0.36	0.64
0:100		0.07	0.24	0.16	0.39	0.25	0.53	0.29	0.57
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.43	0.05	0.44	0.05	0.47	0.05	0.49	0.05
70:30		0.74	0.14	0.79	0.14	0.87	0.14	0.90	0.14
50:50	SBL1	0.82	0.23	0.84	0.23	0.81	0.23	0.80	0.23
30:70		0.65	0.32	0.63	0.32	0.62	0.32	0.62	0.32
10:90		0.54	0.41	0.53	0.41	0.52	0.41	0.52	0.41
0:100		0.50	0.46	0.49	0.46	0.48	0.46	0.49	0.42
100:0		0.47	0.11	0.72	0.22	0.92	0.39	0.98	0.40
90:10		0.44	0.11	0.69	0.23	0.88	0.42	0.95	0.41
70:30		0.56	0.12	0.72	0.24	0.82	0.37	0.88	0.43
50:50	EBL1	0.74	0.13	0.89	0.28	0.99	0.39	1.04	0.45
30:70		0.89	0.16	1.03	0.31	1.16	0.45	1.21	0.49
10:90		1.02	0.20	1.18	0.37	1.35	0.51	1.38	0.54
0:100		1.02	0.24	1.24	0.39	1.35	0.53	1.44	0.57
100:0		0.67	0.68	0.81	0.73	0.96	0.89	1.05	0.82
90:10		0.64	0.73	0.76	0.78	0.92	1.00	0.99	0.85
70:30		0.50	0.74	0.65	0.81	0.80	0.90	0.87	0.94
50:50	NBT2	0.36	0.62	0.49	0.72	0.67	0.77	0.72	0.84
30:70		0.23	0.50	0.34	0.60	0.45	0.71	0.50	0.75
10:90		0.12	0.33	0.20	0.48	0.28	0.59	0.32	0.63
0:100		0.07	0.22	0.13	0.39	0.21	0.52	0.24	0.56
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.36	0.05	0.36	0.05	0.41	0.05	0.44	0.05
70:30		0.55	0.14	0.63	0.14	0.72	0.14	0.74	0.14
50:50	NBL2	0.66	0.23	0.75	0.23	0.81	0.23	0.85	0.23
30:70		0.58	0.32	0.58	0.32	0.60	0.32	0.62	0.32
10:90		0.44	0.41	0.44	0.41	0.46	0.41	0.46	0.41
0:100		0.40	0.46	0.41	0.46	0.41	0.46	0.44	0.43
100:0		0.59	1.29	0.62	1.40	0.65	1.53	0.67	1.59
90:10		0.74	1.12	0.73	1.20	0.74	1.33	0.75	1.38
70:30		0.70	0.79	0.72	0.86	0.77	0.95	0.74	0.98
50:50	SBT2	1.03	0.69	1.11	0.77	1.22	0.85	1.28	0.85
30:70		1.56	0.68	1.73	0.72	1.90	0.81	1.96	0.82
10:90		2.26	0.80	2.44	0.85	2.66	0.93	2.74	0.97
0:100		2.63	0.85	2.86	0.89	3.12	0.99	3.19	1.03
100:0		0.47	0.11	0.72	0.22	0.92	0.35	0.98	0.40
90:10		0.44	0.11	0.69	0.23	0.88	0.35	0.96	0.40
70:30		0.45	0.12	0.65	0.24	0.79	0.37	0.88	0.42
50:50	WBL2	0.54	0.13	0.74	0.27	0.83	0.38	0.88	0.45
30:70		0.66	0.16	0.80	0.30	0.92	0.44	0.96	0.49
10:90		0.75	0.19	0.88	0.36	1.01	0.49	1.07	0.53
0:100		0.80	0.22	0.95	0.39	1.07	0.52	1.12	0.56
100:0		0.64	0.91	0.79	0.96	0.95	1.09	1.03	1.05
90:10		0.69	0.88	0.74	0.93	0.91	1.10	0.98	1.01
70:30		0.78	0.75	0.84	0.82	0.91	0.91	0.94	0.95
50:50	Int v/c	0.83	0.65	0.91	0.73	0.98	0.80	1.02	0.84
30:70		1.02	0.59	1.08	0.66	1.16	0.74	1.19	0.77
10:90		1.18	0.60	1.24	0.67	1.33	0.75	1.36	0.78
0:100		1.27	0.62	1.34	0.67	1.41	0.75	1.46	0.78

Table D-4: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2500 vph with different off-ramp demands and through/left proportions for LC1

Proportion	Approach	JC Volume 2500 vph							
		CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0		0.64	1.38	0.66	1.48	0.70	1.61	0.71	1.67
90:10		0.90	1.17	0.92	1.29	0.93	1.40	0.96	1.42
70:30		0.95	0.83	1.01	0.90	1.11	0.98	1.14	1.03
50:50	NBT1	0.80	0.71	0.88	0.78	0.94	0.86	0.98	0.90
30:70		1.35	0.70	1.47	0.77	1.58	0.82	1.62	0.86
10:90		2.03	0.84	2.13	0.90	2.25	0.97	2.31	1.00
0:100		2.25	0.86	2.37	0.95	2.50	1.02	2.57	1.05
100:0		0.72	0.69	0.84	0.74	1.01	0.81	1.06	0.83
90:10		0.67	0.74	0.81	0.78	0.96	0.84	1.03	0.88
70:30		0.51	0.79	0.65	0.87	0.85	0.94	0.93	0.95
50:50	SBT1	0.36	0.66	0.49	0.78	0.64	0.85	0.72	0.89
30:70		0.24	0.57	0.35	0.65	0.49	0.75	0.52	0.77
10:90		0.13	0.36	0.22	0.50	0.32	0.61	0.35	0.66
0:100		0.07	0.23	0.16	0.40	0.24	0.54	0.27	0.58
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.47	0.05	0.53	0.05	0.50	0.05	0.50	0.05
70:30		0.75	0.15	0.83	0.15	0.92	0.15	0.93	0.15
50:50	SBL1	0.85	0.25	0.84	0.25	0.82	0.25	0.81	0.25
30:70		0.65	0.35	0.64	0.35	0.63	0.35	0.62	0.35
10:90		0.54	0.45	0.54	0.45	0.52	0.45	0.52	0.42
0:100		0.52	0.50	0.50	0.50	0.50	0.46	0.50	0.44
100:0		0.47	0.11	0.78	0.23	0.94	0.35	1.03	0.40
90:10		0.45	0.11	0.73	0.23	0.91	0.36	0.98	0.41
70:30		0.57	0.12	0.76	0.25	0.87	0.38	0.92	0.43
50:50	EBL1	0.80	0.13	0.92	0.28	1.04	0.40	1.10	0.45
30:70		0.94	0.17	1.08	0.31	1.23	0.45	1.28	0.49
10:90		1.02	0.20	1.24	0.37	1.40	0.50	1.43	0.55
0:100		1.02	0.23	1.24	0.40	1.40	0.54	1.43	0.58
100:0		0.72	0.69	0.84	0.75	1.01	0.81	1.06	0.84
90:10		0.67	0.75	0.83	0.78	0.96	0.84	1.03	0.88
70:30		0.52	0.78	0.64	0.86	0.80	0.96	0.85	0.95
50:50	NBT2	0.37	0.65	0.51	0.76	0.65	0.84	0.71	0.88
30:70		0.25	0.55	0.34	0.65	0.45	0.74	0.49	0.76
10:90		0.12	0.36	0.19	0.50	0.27	0.61	0.31	0.65
0:100		0.07	0.22	0.13	0.40	0.20	0.52	0.24	0.57
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.40	0.05	0.45	0.05	0.43	0.05	0.45	0.05
70:30		0.60	0.15	0.69	0.15	0.75	0.15	0.78	0.15
50:50	NBL2	0.71	0.25	0.80	0.25	0.87	0.25	0.90	0.25
30:70		0.59	0.35	0.58	0.35	0.59	0.35	0.60	0.35
10:90		0.44	0.45	0.45	0.45	0.46	0.45	0.47	0.43
0:100		0.42	0.50	0.42	0.50	0.44	0.47	0.44	0.45
100:0		0.64	1.38	0.66	1.50	0.70	1.64	0.71	1.70
90:10		0.77	1.19	0.81	1.29	0.80	1.42	0.81	1.45
70:30		0.69	0.84	0.74	0.91	0.82	1.00	0.82	1.05
50:50	SBT2	1.08	0.72	1.19	0.80	1.29	0.87	1.34	0.91
30:70		1.72	0.72	1.83	0.77	2.00	0.84	2.10	0.88
10:90		2.42	0.84	2.61	0.90	2.89	0.97	2.95	1.02
0:100		2.81	0.88	3.10	0.95	3.33	1.04	3.40	1.07
100:0		0.47	0.11	0.78	0.22	0.94	0.35	1.03	0.40
90:10		0.45	0.11	0.69	0.23	0.91	0.36	0.98	0.41
70:30		0.52	0.12	0.69	0.24	0.82	0.38	0.90	0.43
50:50	WBL2	0.63	0.13	0.77	0.27	0.88	0.40	0.93	0.45
30:70		0.72	0.16	0.85	0.31	0.99	0.44	1.03	0.49
10:90		0.80	0.20	0.95	0.37	1.07	0.50	1.13	0.54
0:100		0.87	0.22	0.99	0.40	1.13	0.52	1.18	0.57
100:0		0.69	0.95	0.83	1.00	0.99	1.07	1.05	1.10
90:10		0.72	0.92	0.80	0.96	0.94	1.03	1.02	1.06
70:30		0.81	0.80	0.88	0.88	0.97	0.97	1.00	0.98
50:50	Int v/c	0.89	0.68	0.97	0.77	1.04	0.85	1.08	0.89
30:70		1.10	0.64	1.14	0.70	1.22	0.78	1.25	0.81
10:90		1.26	0.65	1.33	0.72	1.41	0.78	1.44	0.82
0:100		1.36	0.65	1.43	0.72	1.52	0.79	1.55	0.82

Table D-5: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street volume of 2700 vph with different off-ramp demands and through/left proportions for LC1

JC Volume 2700 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.67	1.47	0.70	1.59	0.74	1.71
90:10		0.91	1.27	0.94	1.37	1.01	1.48
70:30		0.99	0.90	1.07	0.97	1.13	1.05
50:50		0.86	0.78	0.92	0.83	1.01	0.91
30:70		1.45	0.74	1.55	0.80	1.66	0.86
10:90		2.08	0.87	2.19	0.91	2.30	1.01
0:100		2.31	0.88	2.43	0.96	2.56	1.05
100:0	SBT1	0.74	0.70	0.88	0.74	1.05	0.82
90:10		0.71	0.74	0.84	0.79	0.99	0.85
70:30		0.53	0.83	0.68	0.92	0.86	0.96
50:50		0.38	0.74	0.50	0.80	0.66	0.89
30:70		0.25	0.60	0.36	0.68	0.47	0.76
10:90		0.13	0.37	0.21	0.52	0.30	0.63
0:100		0.07	0.24	0.14	0.42	0.23	0.55
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.54	0.05	0.57	0.05	0.51	0.05
70:30		0.79	0.16	0.89	0.16	0.95	0.16
50:50		0.84	0.27	0.83	0.27	0.81	0.27
30:70		0.66	0.38	0.65	0.38	0.63	0.38
10:90		0.55	0.49	0.55	0.49	0.55	0.45
0:100		0.53	0.54	0.53	0.54	0.52	0.48
100:0	EBL1	0.57	0.11	0.79	0.23	0.99	0.36
90:10		0.47	0.11	0.76	0.23	0.94	0.36
70:30		0.63	0.12	0.80	0.25	0.91	0.38
50:50		0.83	0.14	1.00	0.27	1.09	0.41
30:70		1.02	0.17	1.18	0.31	1.31	0.44
10:90		1.02	0.20	1.24	0.38	1.40	0.51
0:100		1.02	0.24	1.24	0.42	1.40	0.55
100:0	NBT2	0.74	0.70	0.88	0.75	1.05	0.82
90:10		0.71	0.75	0.84	0.79	0.95	0.85
70:30		0.54	0.83	0.64	0.92	0.80	0.96
50:50		0.39	0.72	0.51	0.79	0.63	0.88
30:70		0.25	0.58	0.34	0.67	0.44	0.76
10:90		0.13	0.39	0.19	0.51	0.27	0.62
0:100		0.07	0.23	0.13	0.41	0.20	0.54
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.44	0.05	0.46	0.05	0.44	0.05
70:30		0.64	0.16	0.71	0.16	0.81	0.16
50:50		0.76	0.27	0.83	0.27	0.86	0.27
30:70		0.57	0.38	0.59	0.38	0.60	0.38
10:90		0.45	0.49	0.47	0.49	0.48	0.46
0:100		0.43	0.54	0.45	0.54	0.46	0.49
100:0	SBT2	0.67	1.50	0.70	1.62	0.74	1.74
90:10		0.80	1.29	0.82	1.39	0.85	1.51
70:30		0.72	0.90	0.80	0.97	0.83	1.06
50:50		1.14	0.80	1.25	0.84	1.37	0.93
30:70		1.79	0.76	1.94	0.82	2.13	0.88
10:90		2.61	0.85	2.78	0.93	3.02	1.02
0:100		3.04	0.90	3.24	0.98	3.53	1.06
100:0	WBL2	0.57	0.11	0.79	0.22	0.99	0.35
90:10		0.47	0.11	0.76	0.23	0.94	0.36
70:30		0.57	0.12	0.72	0.25	0.84	0.38
50:50		0.67	0.14	0.81	0.27	0.92	0.40
30:70		0.80	0.16	0.92	0.31	1.04	0.44
10:90		0.87	0.21	1.03	0.36	1.16	0.50
0:100		0.94	0.23	1.08	0.41	1.19	0.54
100:0	Int v/c	0.72	1.00	0.86	1.05	1.04	1.12
90:10		0.76	0.96	0.82	1.01	0.98	1.07
70:30		0.86	0.86	0.94	0.94	1.01	0.99
50:50		0.94	0.75	1.02	0.81	1.09	0.89
30:70		1.14	0.67	1.21	0.74	1.28	0.81
10:90		1.35	0.68	1.41	0.74	1.50	0.82
0:100		1.46	0.68	1.53	0.75	1.61	0.82

D.1.2 Plots of difference between CDI and DDI v/c ratios

The following plots present the difference in the CDI and DDI v/c ratios on different turning movements, traffic demands, and through/left proportions for LC1. Number in the legend represent different cross street and off-ramp volumes, i.e. 2300/1100 means cross street demand of 2300 vph and off-ramp volume of 1100 vph.

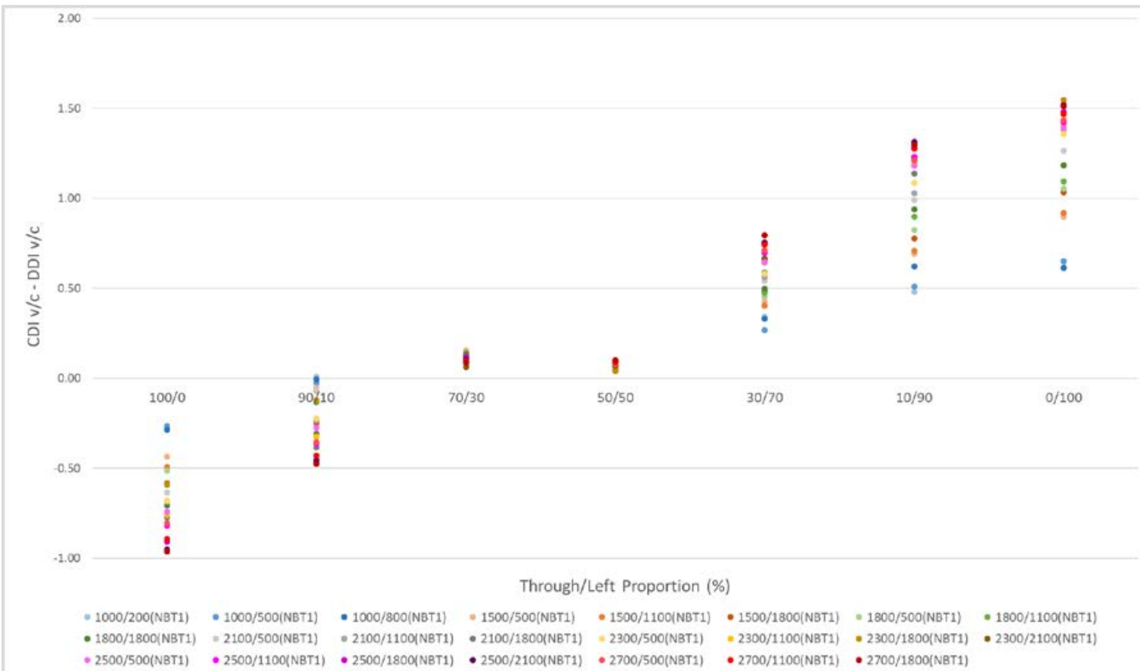


Figure D-1: Difference in v/c ratios between CDI and DDI on NBT1 at different traffic demands and through/left proportions for LC1

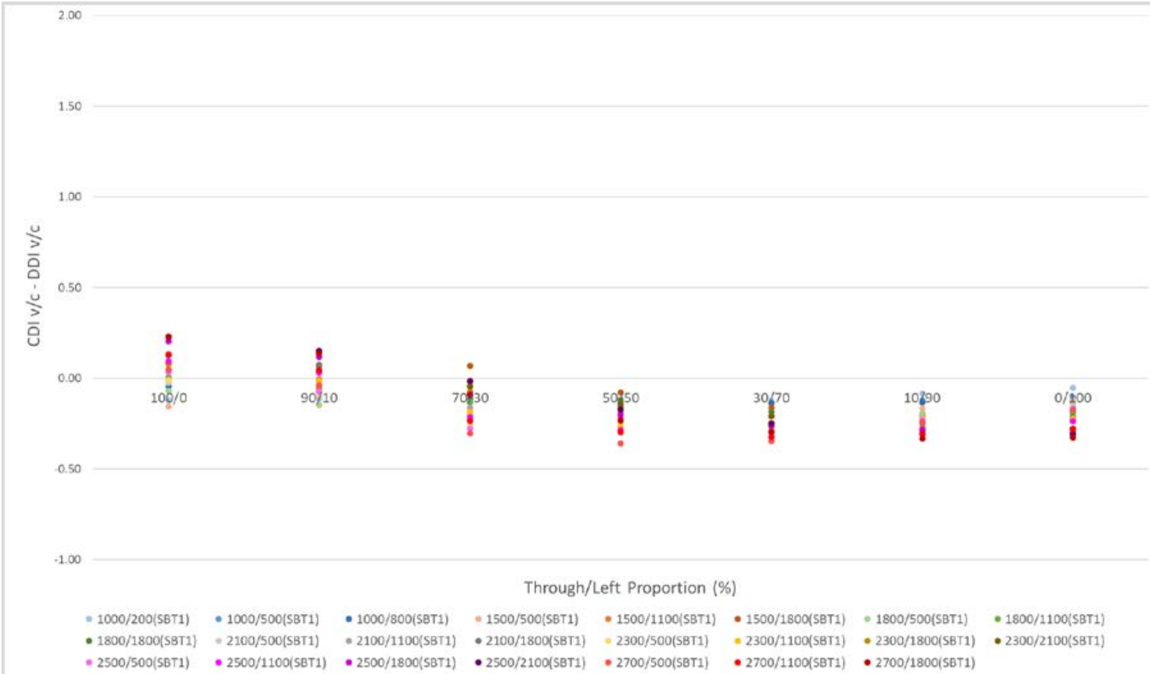


Figure D-2: Difference in v/c ratios between CDI and DDI on SBT1 at different traffic demands and through/left proportions for LC1

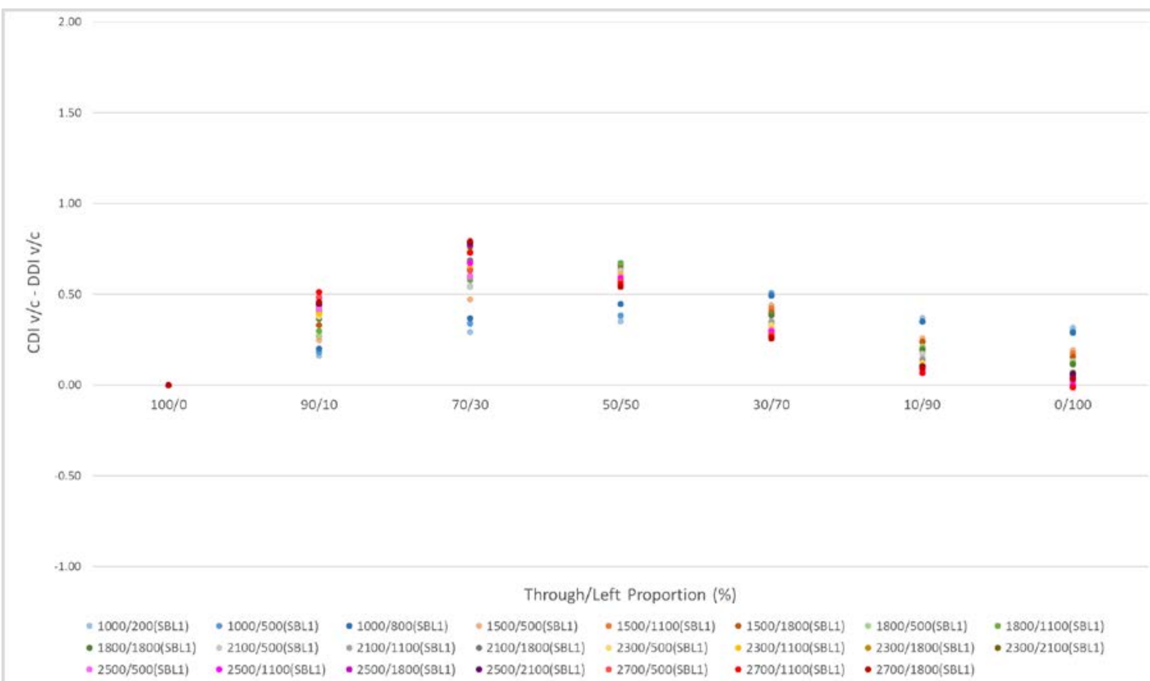


Figure D-3: Difference in v/c ratios between CDI and DDI on SBL1 at different traffic demands and through/left proportions for LC1

Figure D-4: Difference in v/c ratios between CDI and DDI on EBL1 at different traffic demands and through/left proportions for LC1

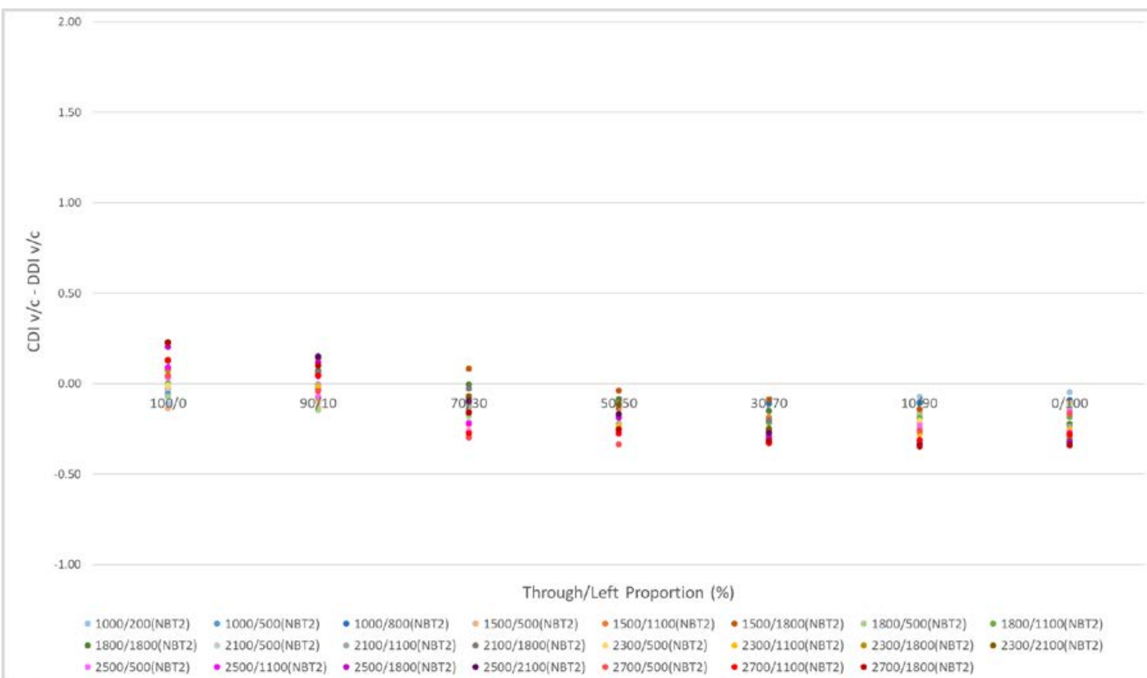


Figure D-5: Difference in v/c ratios between CDI and DDI on NBT2 at different traffic demands and through/left proportions for LC1

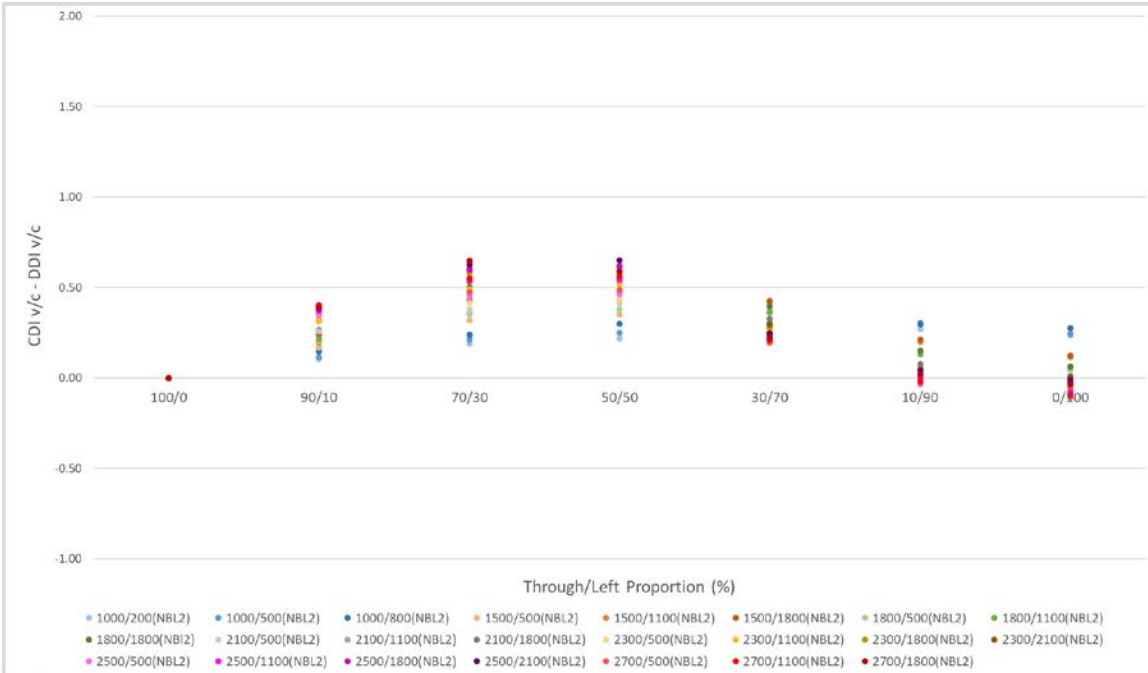
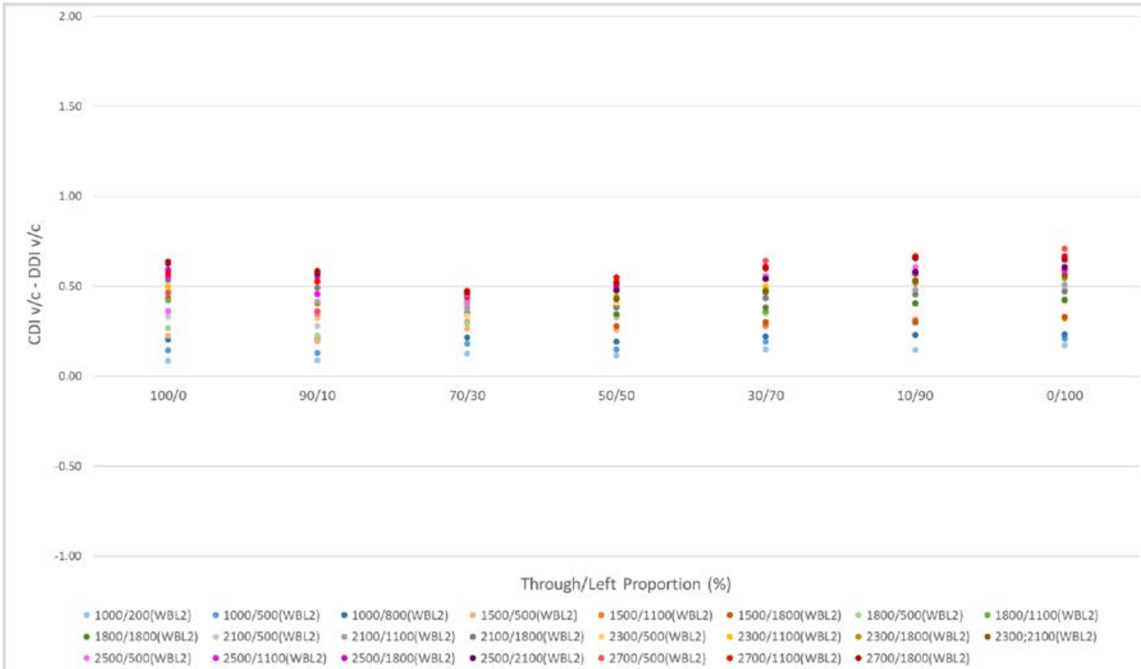


Figure D-6: Difference in v/c ratios between CDI and DDI on NBL2 at different traffic demands and through/left proportions for LC1

Figure D-7: Difference in v/c ratios between CDI and DDI on SBT2 at different traffic demands and through/left proportions for LC1

Figure D-8: Difference in v/c ratios between CDI and DDI on WBL2 at different traffic demands and through/left proportions for LC1



D.2 Lane Configuration 2

The following tables and plots present the difference in the CDI and DDI v/c ratios on different turning movements, traffic demands, and through/left proportions for LC2.

D.2.1 Color-Coded Tables of v/c ratios of CDIs and DDIs

Table D-6: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1000 vph (b) cross street demand of 1500 vph with different off-ramp demands and through/left proportions for LC2

(a)

Proportion	Approach	JC Volume 1000 vph					
		CDI	DDI	CDI	DDI	CDI	DDI
		200 vph		500 vph		800 vph	
100:0	NBT1	0.28	0.54	0.33	0.60	0.35	0.63
90:10		0.45	0.47	0.50	0.51	0.56	0.56
70:30		0.42	0.35	0.47	0.39	0.50	0.41
50:50		0.67	0.45	0.71	0.50	0.79	0.53
30:70		1.03	0.58	1.15	0.64	1.15	0.70
10:90		1.55	0.67	1.61	0.75	1.71	0.82
0:100		1.78	0.69	1.92	0.80	1.96	0.91
100:0	SBT1	0.32	0.45	0.44	0.51	0.52	0.56
90:10		0.30	0.44	0.39	0.49	0.49	0.53
70:30		0.23	0.39	0.31	0.44	0.39	0.50
50:50		0.16	0.33	0.23	0.39	0.30	0.45
30:70		0.11	0.25	0.16	0.32	0.22	0.38
10:90		0.06	0.16	0.11	0.24	0.16	0.32
0:100		0.03	0.09	0.08	0.20	0.13	0.26
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.20	0.04	0.22	0.04	0.23	0.04
70:30		0.36	0.12	0.43	0.12	0.46	0.12
50:50		0.50	0.20	0.55	0.20	0.58	0.20
30:70		0.52	0.28	0.50	0.28	0.56	0.28
10:90		0.43	0.36	0.43	0.36	0.42	0.36
0:100		0.40	0.40	0.39	0.40	0.38	0.38
100:0	EBL1	0.13	0.05	0.26	0.12	0.38	0.19
90:10		0.16	0.05	0.28	0.13	0.38	0.19
70:30		0.19	0.06	0.35	0.14	0.45	0.21
50:50		0.25	0.07	0.42	0.15	0.50	0.23
30:70		0.29	0.07	0.45	0.16	0.58	0.24
10:90		0.32	0.09	0.53	0.18	0.62	0.26
0:100		0.33	0.09	0.55	0.20	0.66	0.26
100:0	NBT2	0.32	0.44	0.44	0.49	0.52	0.55
90:10		0.30	0.42	0.39	0.47	0.48	0.53
70:30		0.22	0.38	0.30	0.42	0.38	0.49
50:50		0.16	0.31	0.23	0.37	0.30	0.43
30:70		0.11	0.24	0.16	0.31	0.22	0.36
10:90		0.06	0.15	0.11	0.23	0.16	0.29
0:100		0.03	0.09	0.08	0.17	0.13	0.24
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.18	0.04	0.20	0.04	0.22	0.04
70:30		0.36	0.12	0.40	0.12	0.45	0.12
50:50		0.48	0.20	0.52	0.20	0.56	0.20
30:70		0.53	0.28	0.51	0.28	0.56	0.28
10:90		0.44	0.36	0.43	0.36	0.42	0.36
0:100		0.41	0.40	0.38	0.40	0.38	0.40
100:0	SBT2	0.28	0.56	0.33	0.63	0.35	0.67
90:10		0.47	0.49	0.53	0.54	0.57	0.57
70:30		0.40	0.37	0.47	0.41	0.50	0.43
50:50		0.71	0.48	0.75	0.53	0.82	0.56
30:70		1.09	0.61	1.19	0.67	1.15	0.74
10:90		1.61	0.69	1.65	0.78	1.69	0.90
0:100		1.90	0.71	1.86	0.87	1.95	1.00
100:0	WBL2	0.13	0.05	0.26	0.12	0.38	0.18
90:10		0.16	0.05	0.28	0.12	0.38	0.19
70:30		0.21	0.06	0.39	0.13	0.47	0.20
50:50		0.25	0.06	0.42	0.14	0.50	0.22
30:70		0.29	0.07	0.46	0.16	0.58	0.23
10:90		0.33	0.08	0.53	0.17	0.63	0.24
0:100		0.34	0.09	0.57	0.17	0.67	0.24
100:0	Int v/c	0.28	0.48	0.39	0.53	0.48	0.58
90:10		0.32	0.44	0.36	0.49	0.45	0.53
70:30		0.36	0.36	0.42	0.41	0.47	0.45
50:50		0.53	0.39	0.58	0.43	0.63	0.48
30:70		0.68	0.43	0.69	0.48	0.74	0.52
10:90		0.76	0.48	0.77	0.53	0.78	0.57
0:100		0.80	0.49	0.78	0.55	0.80	0.60

(b)

Proportion	Approach	JC Volume 1500 vph					
		CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.45	0.86	0.47	0.94	0.48	1.07
90:10		0.68	0.74	0.63	0.81	0.64	0.90
70:30		0.59	0.53	0.67	0.60	0.68	0.64
50:50		0.96	0.71	1.06	0.78	1.15	0.90
30:70		1.50	0.91	1.67	1.05	1.76	1.09
10:90		2.19	1.04	2.37	1.23	2.56	1.30
0:100		2.55	1.06	2.77	1.36	3.00	1.44
100:0	SBT1	0.55	0.67	0.69	0.74	0.83	0.79
90:10		0.50	0.63	0.65	0.72	0.81	0.83
70:30		0.37	0.58	0.53	0.67	0.72	0.70
50:50		0.27	0.50	0.41	0.62	0.57	0.73
30:70		0.19	0.42	0.30	0.54	0.45	0.65
10:90		0.11	0.31	0.21	0.44	0.33	0.56
0:100		0.07	0.22	0.17	0.36	0.27	0.52
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.33	0.06	0.41	0.06	0.43	0.06
70:30		0.55	0.18	0.63	0.18	0.68	0.18
50:50		0.71	0.30	0.72	0.30	0.69	0.30
30:70		0.51	0.42	0.49	0.36	0.50	0.34
10:90		0.41	0.48	0.40	0.40	0.39	0.35
0:100		0.36	0.51	0.36	0.40	0.35	0.35
100:0	EBL1	0.35	0.12	0.59	0.23	0.78	0.36
90:10		0.35	0.12	0.53	0.24	0.77	0.38
70:30		0.44	0.13	0.60	0.26	0.69	0.36
50:50		0.55	0.15	0.72	0.29	0.80	0.44
30:70		0.63	0.17	0.78	0.33	0.90	0.46
10:90		0.74	0.21	0.88	0.36	1.01	0.49
0:100		0.82	0.22	0.95	0.36	1.07	0.52
100:0	NBT2	0.55	0.66	0.69	0.73	0.83	0.79
90:10		0.49	0.62	0.65	0.71	0.81	0.81
70:30		0.37	0.56	0.52	0.66	0.72	0.69
50:50		0.27	0.49	0.40	0.59	0.57	0.72
30:70		0.19	0.40	0.30	0.52	0.45	0.61
10:90		0.11	0.29	0.21	0.42	0.33	0.51
0:100		0.07	0.20	0.17	0.34	0.27	0.47
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.30	0.06	0.35	0.06	0.42	0.06
70:30		0.55	0.18	0.63	0.18	0.65	0.18
50:50		0.71	0.30	0.72	0.30	0.69	0.30
30:70		0.52	0.42	0.49	0.38	0.50	0.37
10:90		0.41	0.49	0.39	0.42	0.40	0.39
0:100		0.36	0.54	0.36	0.42	0.36	0.40
100:0	SBT2	0.45	0.89	0.47	0.97	0.48	1.07
90:10		0.68	0.77	0.68	0.84	0.65	0.93
70:30		0.59	0.54	0.64	0.61	0.70	0.66
50:50		0.96	0.72	1.05	0.82	1.15	0.91
30:70		1.56	0.95	1.68	1.11	1.80	1.18
10:90		2.19	1.08	2.31	1.29	2.63	1.45
0:100		2.55	1.13	2.77	1.43	3.09	1.64
100:0	WBL2	0.35	0.11	0.59	0.23	0.78	0.36
90:10		0.39	0.12	0.53	0.24	0.78	0.37
70:30		0.44	0.13	0.64	0.26	0.69	0.36
50:50		0.56	0.14	0.72	0.28	0.81	0.43
30:70		0.63	0.16	0.78	0.31	0.90	0.44
10:90		0.74	0.20	0.92	0.34	1.01	0.45
0:100		0.82	0.20	0.95	0.34	1.07	0.47
100:0	Int v/c	0.51	0.74	0.66	0.80	0.82	0.87
90:10		0.47	0.67	0.62	0.74	0.80	0.84
70:30		0.55	0.54	0.64	0.63	0.71	0.68
50:50		0.78	0.59	0.83	0.68	0.86	0.78
30:70		0.85	0.68	0.87	0.77	0.93	0.83
10:90		0.92	0.75	0.96	0.84	1.03	0.90
0:100		0.95	0.76	1.01	0.88	1.09	0.95

Table D-7: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1800 vph (b) cross street demand of 2100 vph with different off-ramp demands and through/left proportions for LC2

(a)

JC Volume 1800 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.51	1.01	0.52	1.11	0.54	1.20
90:10		0.77	0.86	0.70	0.95	0.78	1.04
70:30		0.68	0.61	0.71	0.69	0.79	0.76
50:50		1.05	0.81	1.17	0.90	1.28	0.99
30:70		1.72	1.05	1.85	1.16	2.06	1.26
10:90		2.56	1.20	2.78	1.35	2.99	1.51
0:100		3.01	1.24	3.22	1.49	3.50	1.68
100:0	SBT1	0.60	0.71	0.72	0.75	0.87	0.78
90:10		0.57	0.74	0.70	0.79	0.86	0.82
70:30		0.42	0.64	0.56	0.73	0.76	0.82
50:50		0.29	0.57	0.42	0.65	0.58	0.75
30:70		0.20	0.50	0.30	0.59	0.44	0.71
10:90		0.11	0.35	0.20	0.47	0.29	0.59
0:100		0.07	0.26	0.14	0.38	0.23	0.51
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.40	0.07	0.48	0.07	0.39	0.07
70:30		0.66	0.22	0.72	0.22	0.80	0.22
50:50		0.69	0.36	0.70	0.36	0.70	0.34
30:70		0.51	0.44	0.51	0.40	0.50	0.37
10:90		0.40	0.49	0.39	0.44	0.39	0.38
0:100		0.35	0.51	0.36	0.44	0.36	0.38
100:0	EBL1	0.38	0.11	0.65	0.23	0.83	0.35
90:10		0.39	0.12	0.58	0.24	0.79	0.36
70:30		0.49	0.13	0.65	0.26	0.78	0.39
50:50		0.63	0.15	0.79	0.28	0.88	0.42
30:70		0.78	0.18	0.92	0.33	1.01	0.48
10:90		0.89	0.22	1.03	0.37	1.16	0.51
0:100		0.94	0.26	1.11	0.38	1.23	0.51
100:0	NBT2	0.60	0.72	0.72	0.75	0.88	0.78
90:10		0.57	0.72	0.70	0.78	0.86	0.82
70:30		0.41	0.63	0.55	0.72	0.75	0.81
50:50		0.29	0.55	0.42	0.65	0.58	0.74
30:70		0.20	0.47	0.30	0.57	0.44	0.69
10:90		0.11	0.33	0.20	0.45	0.29	0.56
0:100		0.07	0.22	0.14	0.36	0.23	0.48
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.38	0.07	0.45	0.07	0.49	0.07
70:30		0.66	0.22	0.69	0.22	0.79	0.22
50:50		0.70	0.36	0.70	0.36	0.69	0.36
30:70		0.51	0.46	0.51	0.41	0.50	0.38
10:90		0.40	0.51	0.39	0.46	0.39	0.41
0:100		0.36	0.55	0.36	0.46	0.36	0.41
100:0	SBT2	0.51	1.03	0.52	1.13	0.54	1.22
90:10		0.79	0.88	0.71	0.97	0.72	1.06
70:30		0.66	0.63	0.72	0.71	0.78	0.79
50:50		1.08	0.84	1.17	0.90	1.25	1.01
30:70		1.72	1.10	1.85	1.21	2.06	1.31
10:90		2.56	1.25	2.78	1.39	2.99	1.61
0:100		3.09	1.33	3.22	1.54	3.50	1.79
100:0	WBL2	0.38	0.11	0.65	0.23	0.82	0.34
90:10		0.39	0.12	0.58	0.23	0.80	0.35
70:30		0.53	0.13	0.67	0.25	0.80	0.38
50:50		0.63	0.14	0.79	0.28	0.90	0.41
30:70		0.78	0.17	0.92	0.32	1.01	0.46
10:90		0.89	0.21	1.03	0.36	1.16	0.48
0:100		0.94	0.22	1.11	0.36	1.23	0.48
100:0	Int v/c	0.56	0.83	0.71	0.88	0.86	0.91
90:10		0.60	0.78	0.67	0.84	0.84	0.89
70:30		0.64	0.62	0.70	0.70	0.76	0.79
50:50		0.83	0.68	0.88	0.75	0.93	0.84
30:70		0.92	0.80	0.96	0.86	1.03	0.95
10:90		1.02	0.89	1.08	0.95	1.16	1.03
0:100		1.08	0.93	1.15	0.99	1.22	1.07

(b)

JC Volume 2100 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.57	1.16	0.58	1.24	0.60	1.35
90:10		0.78	0.98	0.77	1.07	0.79	1.15
70:30		0.72	0.69	0.80	0.77	0.84	0.84
50:50		1.20	0.91	1.30	1.01	1.40	1.11
30:70		1.96	1.18	2.12	1.29	2.35	1.43
10:90		3.02	1.35	3.16	1.46	3.32	1.65
0:100		3.52	1.45	3.69	1.63	3.88	1.84
100:0	SBT1	0.65	0.70	0.77	0.74	0.92	0.81
90:10		0.59	0.77	0.74	0.80	0.89	0.85
70:30		0.44	0.73	0.60	0.81	0.77	0.87
50:50		0.32	0.64	0.44	0.74	0.60	0.83
30:70		0.21	0.59	0.31	0.63	0.41	0.74
10:90		0.11	0.40	0.18	0.54	0.26	0.64
0:100		0.06	0.26	0.13	0.41	0.19	0.54
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.42	0.08	0.51	0.08	0.47	0.08
70:30		0.70	0.25	0.81	0.25	0.86	0.25
50:50		0.69	0.42	0.69	0.39	0.69	0.35
30:70		0.50	0.46	0.50	0.43	0.50	0.39
10:90		0.39	0.51	0.39	0.48	0.40	0.41
0:100		0.35	0.53	0.36	0.48	0.36	0.41
100:0	EBL1	0.44	0.11	0.69	0.23	0.88	0.35
90:10		0.44	0.11	0.65	0.23	0.84	0.36
70:30		0.57	0.13	0.73	0.26	0.83	0.38
50:50		0.73	0.15	0.87	0.29	0.99	0.43
30:70		0.89	0.20	1.03	0.33	1.13	0.47
10:90		0.94	0.24	1.18	0.41	1.31	0.54
0:100		1.02	0.26	1.24	0.41	1.40	0.54
100:0	NBT2	0.65	0.71	0.77	0.75	0.92	0.81
90:10		0.59	0.80	0.74	0.80	0.89	0.85
70:30		0.44	0.71	0.60	0.80	0.77	0.87
50:50		0.32	0.62	0.44	0.73	0.60	0.82
30:70		0.21	0.55	0.31	0.64	0.42	0.74
10:90		0.12	0.37	0.18	0.51	0.26	0.60
0:100		0.06	0.24	0.13	0.39	0.19	0.51
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.39	0.08	0.49	0.08	0.46	0.08
70:30		0.70	0.25	0.79	0.25	0.84	0.25
50:50		0.69	0.42	0.69	0.39	0.69	0.36
30:70		0.50	0.48	0.50	0.43	0.49	0.39
10:90		0.39	0.53	0.39	0.49	0.40	0.43
0:100		0.36	0.55	0.36	0.49	0.37	0.43
100:0	SBT2	0.57	1.18	0.58	1.26	0.60	1.35
90:10		0.80	1.00	0.78	1.09	0.80	1.17
70:30		0.72	0.70	0.81	0.79	0.86	0.86
50:50		1.20	0.93	1.30	1.02	1.43	1.13
30:70		2.00	1.23	2.16	1.29	2.30	1.43
10:90		2.96	1.40	3.16	1.51	3.40	1.76
0:100		3.60	1.50	3.78	1.68	3.98	1.96
100:0	WBL2	0.44	0.11	0.69	0.22	0.88	0.35
90:10		0.44	0.11	0.65	0.23	0.84	0.36
70:30		0.57	0.13	0.74	0.25	0.83	0.38
50:50		0.73	0.14	0.87	0.29	0.99	0.43
30:70		0.89	0.18	1.03	0.33	1.16	0.47
10:90		1.02	0.22	1.18	0.39	1.31	0.51
0:100		1.02	0.24	1.24	0.39	1.40	0.51
100:0	Int v/c	0.62	0.88	0.75	0.92	0.91	0.98
90:10		0.63	0.87	0.72	0.90	0.87	0.96
70:30		0.69	0.70	0.79	0.79	0.84	0.86
50:50		0.89	0.77	0.93	0.85	1.00	0.94
30:70		1.01	0.92	1.06	0.96	1.13	1.04
10:90		1.14	1.02	1.20	1.08	1.28	1.16
0:100		1.21	1.07	1.28	1.13	1.36	1.20

Table D-8: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2300 vph with different off-ramp demands and through/left proportions for LC2

JC Volume 2300 vph									
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0	NBT1	0.59	1.24	0.62	1.34	0.65	1.45	0.67	1.51
90:10		0.81	1.07	0.83	1.15	0.80	1.26	0.82	1.31
70:30		0.74	0.74	0.83	0.82	0.88	0.89	0.93	0.92
50:50		1.27	0.96	1.40	1.11	1.53	1.20	1.56	1.21
30:70		2.15	1.28	2.32	1.37	2.49	1.49	2.58	1.53
10:90		3.24	1.43	3.47	1.57	3.64	1.74	3.73	1.80
0:100		3.68	1.53	3.94	1.67	4.14	1.89	4.25	2.00
100:0	SBT1	0.67	0.71	0.81	0.76	0.96	0.82	1.05	0.85
90:10		0.62	0.77	0.79	0.81	0.92	0.85	1.00	0.88
70:30		0.46	0.76	0.61	0.85	0.79	0.93	0.88	0.97
50:50		0.33	0.69	0.46	0.80	0.59	0.83	0.64	0.88
30:70		0.23	0.58	0.31	0.69	0.40	0.78	0.44	0.82
10:90		0.12	0.40	0.18	0.57	0.25	0.66	0.29	0.69
0:100		0.06	0.28	0.12	0.46	0.18	0.56	0.22	0.58
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.46	0.09	0.62	0.09	0.60	0.09	0.61	0.09
70:30		0.75	0.28	0.86	0.28	0.90	0.28	0.94	0.28
50:50		0.68	0.46	0.68	0.39	0.68	0.36	0.69	0.35
30:70		0.49	0.48	0.49	0.43	0.50	0.40	0.50	0.39
10:90		0.39	0.54	0.39	0.49	0.40	0.44	0.39	0.42
0:100		0.38	0.55	0.37	0.49	0.38	0.44	0.37	0.42
100:0	EBL1	0.47	0.11	0.72	0.23	0.92	0.36	0.98	0.41
90:10		0.45	0.11	0.69	0.23	0.88	0.36	0.95	0.41
70:30		0.62	0.12	0.81	0.25	0.87	0.38	0.91	0.44
50:50		0.80	0.15	0.92	0.30	1.04	0.41	1.10	0.47
30:70		0.94	0.18	1.08	0.34	1.23	0.48	1.28	0.54
10:90		1.02	0.23	1.24	0.43	1.40	0.55	1.43	0.58
0:100		1.13	0.28	1.30	0.46	1.45	0.56	1.48	0.58
100:0	NBT2	0.67	0.71	0.81	0.76	0.96	0.82	1.05	0.85
90:10		0.62	0.77	0.79	0.81	0.92	0.85	0.99	0.88
70:30		0.46	0.75	0.61	0.84	0.79	0.92	0.88	0.97
50:50		0.33	0.68	0.46	0.81	0.59	0.82	0.64	0.87
30:70		0.23	0.58	0.31	0.67	0.40	0.76	0.44	0.80
10:90		0.12	0.39	0.18	0.55	0.25	0.64	0.29	0.66
0:100		0.06	0.26	0.12	0.41	0.18	0.53	0.22	0.56
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.46	0.09	0.59	0.09	0.58	0.09	0.60	0.09
70:30		0.73	0.28	0.84	0.28	0.89	0.28	0.94	0.28
50:50		0.69	0.46	0.68	0.39	0.68	0.37	0.69	0.36
30:70		0.50	0.48	0.49	0.45	0.50	0.41	0.50	0.40
10:90		0.39	0.55	0.39	0.50	0.40	0.45	0.40	0.44
0:100		0.38	0.57	0.37	0.52	0.38	0.46	0.38	0.44
100:0	SBT2	0.59	1.25	0.62	1.36	0.65	1.48	0.67	1.53
90:10		0.81	1.09	0.84	1.16	0.81	1.28	0.82	1.33
70:30		0.75	0.75	0.85	0.83	0.90	0.91	0.93	0.93
50:50		1.29	0.99	1.40	1.11	1.53	1.22	1.59	1.23
30:70		2.19	1.28	2.37	1.41	2.49	1.53	2.58	1.57
10:90		3.31	1.44	3.47	1.60	3.64	1.79	3.82	1.88
0:100		3.68	1.59	3.94	1.78	4.14	1.99	4.36	2.09
100:0	WBL2	0.47	0.11	0.72	0.23	0.92	0.35	0.98	0.40
90:10		0.45	0.11	0.69	0.23	0.88	0.36	0.96	0.41
70:30		0.63	0.12	0.81	0.25	0.87	0.38	0.91	0.43
50:50		0.80	0.14	0.92	0.30	1.04	0.41	1.10	0.46
30:70		0.94	0.18	1.08	0.33	1.23	0.47	1.28	0.53
10:90		1.02	0.23	1.24	0.41	1.40	0.53	1.43	0.56
0:100		1.13	0.26	1.30	0.41	1.45	0.53	1.48	0.56
100:0	Int v/c	0.64	0.92	0.79	0.97	0.95	1.03	1.03	1.06
90:10		0.67	0.89	0.77	0.94	0.91	0.99	0.98	1.02
70:30		0.73	0.75	0.84	0.83	0.89	0.91	0.93	0.95
50:50		0.93	0.83	0.97	0.93	1.04	0.98	1.07	1.01
30:70		1.06	0.97	1.12	1.04	1.20	1.11	1.23	1.14
10:90		1.21	1.08	1.28	1.17	1.36	1.22	1.39	1.24
0:100		1.31	1.17	1.37	1.22	1.45	1.27	1.49	1.29

Table D-9: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2500 vph with different off-ramp demands and through/left proportions for LC2

JC Volume 2500 vph									
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0		0.65	1.34	0.65	1.45	0.70	1.55	0.71	1.61
90:10		0.88	1.14	0.86	1.25	0.87	1.35	0.89	1.40
70:30		0.78	0.80	0.88	0.88	0.94	0.95	0.97	0.98
50:50	NBT1	1.41	1.06	1.50	1.16	1.64	1.23	1.70	1.27
30:70		2.38	1.35	2.47	1.44	2.68	1.56	2.74	1.62
10:90		3.45	1.50	3.60	1.66	3.86	1.80	3.95	1.86
0:100		3.83	1.61	4.00	1.75	4.29	2.00	4.39	2.08
100:0		0.73	0.71	0.83	0.76	1.01	0.84	1.06	0.87
90:10		0.68	0.78	0.81	0.82	0.96	0.87	1.03	0.90
70:30		0.48	0.81	0.63	0.89	0.81	0.99	0.90	1.00
50:50	SBT1	0.36	0.78	0.47	0.83	0.59	0.91	0.64	0.93
30:70		0.23	0.64	0.31	0.72	0.40	0.82	0.44	0.84
10:90		0.11	0.45	0.18	0.57	0.25	0.69	0.27	0.71
0:100		0.06	0.31	0.12	0.46	0.18	0.56	0.21	0.60
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.54	0.10	0.65	0.10	0.61	0.10	0.62	0.10
70:30		0.79	0.30	0.88	0.30	0.95	0.30	1.00	0.30
50:50	SBL1	0.69	0.43	0.69	0.41	0.69	0.38	0.68	0.37
30:70		0.50	0.48	0.49	0.46	0.50	0.42	0.50	0.40
10:90		0.40	0.55	0.40	0.50	0.41	0.46	0.41	0.44
0:100		0.40	0.55	0.40	0.52	0.41	0.46	0.41	0.44
100:0		0.50	0.11	0.77	0.23	0.94	0.36	1.03	0.41
90:10		0.49	0.11	0.73	0.23	0.91	0.36	0.98	0.42
70:30		0.66	0.12	0.80	0.25	0.92	0.39	0.96	0.44
50:50	EBL1	0.80	0.16	0.99	0.29	1.09	0.43	1.15	0.48
30:70		0.94	0.19	1.18	0.34	1.31	0.49	1.35	0.53
10:90		1.13	0.25	1.30	0.42	1.45	0.56	1.52	0.59
0:100		1.13	0.31	1.30	0.46	1.45	0.56	1.52	0.60
100:0		0.73	0.71	0.83	0.76	1.01	0.84	1.06	0.87
90:10		0.68	0.78	0.82	0.82	0.96	0.87	1.03	0.90
70:30		0.48	0.81	0.63	0.89	0.81	0.98	0.90	1.02
50:50	NBT2	0.35	0.75	0.47	0.83	0.59	0.89	0.64	0.92
30:70		0.24	0.61	0.31	0.71	0.40	0.80	0.44	0.83
10:90		0.11	0.42	0.18	0.55	0.25	0.67	0.27	0.68
0:100		0.06	0.26	0.12	0.42	0.18	0.55	0.21	0.58
100:0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.54	0.10	0.62	0.10	0.60	0.10	0.61	0.10
70:30		0.79	0.30	0.88	0.30	0.95	0.30	0.98	0.30
50:50	NBL2	0.68	0.45	0.69	0.41	0.68	0.39	0.68	0.37
30:70		0.49	0.49	0.50	0.46	0.50	0.43	0.50	0.41
10:90		0.40	0.57	0.41	0.52	0.41	0.48	0.41	0.46
0:100		0.40	0.59	0.41	0.54	0.41	0.48	0.41	0.46
100:0		0.65	1.36	0.65	1.48	0.70	1.58	0.71	1.64
90:10		0.88	1.16	0.88	1.25	0.87	1.37	0.90	1.42
70:30		0.78	0.80	0.88	0.88	0.94	0.97	0.98	1.00
50:50	SBT2	1.38	1.09	1.50	1.16	1.64	1.25	1.70	1.29
30:70		2.33	1.40	2.52	1.45	2.68	1.59	2.74	1.65
10:90		3.45	1.54	3.68	1.70	3.86	1.84	3.95	1.93
0:100		3.83	1.72	4.09	1.84	4.29	2.05	4.39	2.14
100:0		0.50	0.11	0.77	0.23	0.94	0.36	1.03	0.41
90:10		0.49	0.11	0.70	0.23	0.91	0.36	0.98	0.41
70:30		0.67	0.12	0.80	0.25	0.92	0.38	0.96	0.44
50:50	WBL2	0.87	0.15	0.99	0.29	1.13	0.42	1.15	0.47
30:70		1.02	0.18	1.18	0.34	1.31	0.48	1.35	0.53
10:90		1.13	0.23	1.30	0.40	1.45	0.55	1.52	0.57
0:100		1.13	0.26	1.30	0.42	1.45	0.55	1.52	0.58
100:0		0.69	0.96	0.82	1.01	0.99	1.08	1.05	1.11
90:10		0.74	0.93	0.80	0.97	0.94	1.04	1.02	1.07
70:30		0.77	0.80	0.86	0.88	0.94	0.97	0.98	1.01
50:50	Int v/c	0.97	0.92	1.02	0.97	1.09	1.04	1.12	1.07
30:70		1.12	1.05	1.19	1.10	1.26	1.17	1.29	1.19
10:90		1.30	1.17	1.37	1.23	1.44	1.29	1.48	1.30
0:100		1.40	1.26	1.47	1.28	1.55	1.34	1.58	1.36

Table D-10: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2700 vph with different off-ramp demands and through/left proportions for LC2

JC Volume 2700 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.67	1.45	0.70	1.54	0.74	1.68
90:10		0.90	1.23	0.88	1.33	0.93	1.43
70:30		0.86	0.86	0.91	0.92	0.99	1.02
50:50		1.50	1.10	1.62	1.20	1.74	1.29
30:70		2.52	1.39	2.67	1.54	2.84	1.65
10:90		3.50	1.58	3.72	1.69	3.89	1.87
0:100		3.89	1.69	4.14	1.84	4.32	2.04
100:0	SBT1	0.74	0.71	0.88	0.77	1.05	0.85
90:10		0.71	0.78	0.82	0.82	0.99	0.89
70:30		0.52	0.87	0.65	0.96	0.81	0.99
50:50		0.38	0.81	0.48	0.86	0.59	0.94
30:70		0.25	0.68	0.32	0.76	0.40	0.84
10:90		0.12	0.45	0.18	0.61	0.24	0.72
0:100		0.06	0.35	0.11	0.46	0.18	0.59
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.58	0.11	0.61	0.11	0.63	0.11
70:30		0.88	0.32	0.91	0.32	1.02	0.32
50:50		0.68	0.45	0.69	0.42	0.69	0.39
30:70		0.49	0.50	0.50	0.47	0.50	0.43
10:90		0.43	0.58	0.44	0.53	0.45	0.48
0:100		0.43	0.57	0.44	0.55	0.45	0.48
100:0	EBL1	0.57	0.11	0.78	0.23	0.99	0.36
90:10		0.50	0.11	0.74	0.24	0.94	0.37
70:30		0.68	0.12	0.85	0.26	0.98	0.39
50:50		0.87	0.15	1.03	0.29	1.16	0.43
30:70		1.02	0.19	1.24	0.35	1.40	0.49
10:90		1.13	0.24	1.30	0.44	1.50	0.58
0:100		1.13	0.35	1.30	0.46	1.50	0.59
100:0	NBT2	0.74	0.71	0.88	0.78	1.05	0.85
90:10		0.71	0.78	0.82	0.83	0.99	0.89
70:30		0.52	0.86	0.65	0.95	0.83	0.99
50:50		0.38	0.79	0.48	0.84	0.59	0.93
30:70		0.25	0.65	0.32	0.76	0.40	0.83
10:90		0.12	0.45	0.18	0.59	0.24	0.70
0:100		0.06	0.28	0.12	0.44	0.18	0.56
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.58	0.11	0.59	0.11	0.61	0.11
70:30		0.86	0.32	0.91	0.32	1.00	0.32
50:50		0.68	0.46	0.68	0.43	0.68	0.40
30:70		0.49	0.52	0.50	0.47	0.50	0.43
10:90		0.44	0.58	0.43	0.55	0.45	0.49
0:100		0.44	0.61	0.43	0.56	0.45	0.50
100:0	SBT2	0.67	1.47	0.70	1.57	0.74	1.68
90:10		0.90	1.25	0.88	1.35	0.94	1.46
70:30		0.87	0.86	0.91	0.93	1.00	1.03
50:50		1.52	1.13	1.59	1.22	1.74	1.31
30:70		2.57	1.43	2.67	1.54	2.84	1.66
10:90		3.57	1.58	3.72	1.73	3.89	1.91
0:100		3.97	1.80	4.14	1.88	4.32	2.12
100:0	WBL2	0.57	0.11	0.79	0.23	0.99	0.36
90:10		0.50	0.11	0.75	0.23	0.94	0.36
70:30		0.68	0.12	0.85	0.25	0.98	0.39
50:50		0.87	0.15	1.08	0.28	1.19	0.42
30:70		1.02	0.18	1.24	0.35	1.40	0.49
10:90		1.13	0.24	1.38	0.42	1.50	0.56
0:100		1.13	0.28	1.38	0.44	1.50	0.56
100:0	Int v/c	0.72	1.00	0.86	1.06	1.04	1.12
90:10		0.77	0.97	0.80	1.02	0.98	1.08
70:30		0.85	0.86	0.90	0.94	1.00	1.00
50:50		1.01	0.96	1.07	1.02	1.14	1.09
30:70		1.18	1.11	1.25	1.17	1.32	1.23
10:90		1.39	1.23	1.45	1.29	1.54	1.36
0:100		1.51	1.36	1.57	1.35	1.65	1.42

D.2.2 Plots of difference between CDI and DDI v/c ratios

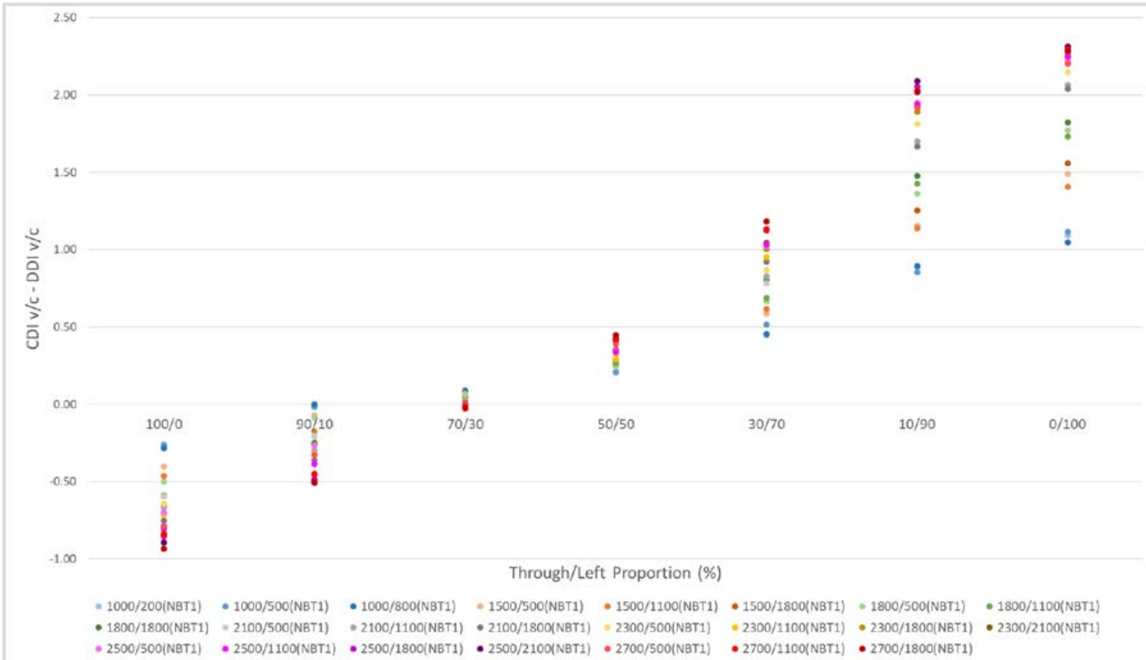


Figure D-9: Difference in v/c ratios between CDI and DDI on NBT1 at different traffic demands and through/left proportions for LC2

Figure D-10: Difference in v/c ratios between CDI and DDI on SBT1 at different traffic demands and through/left proportions for LC2

Figure D-11: Difference in v/c ratios between CDI and DDI on SBL1 at different traffic demands and through/left proportions for LC2

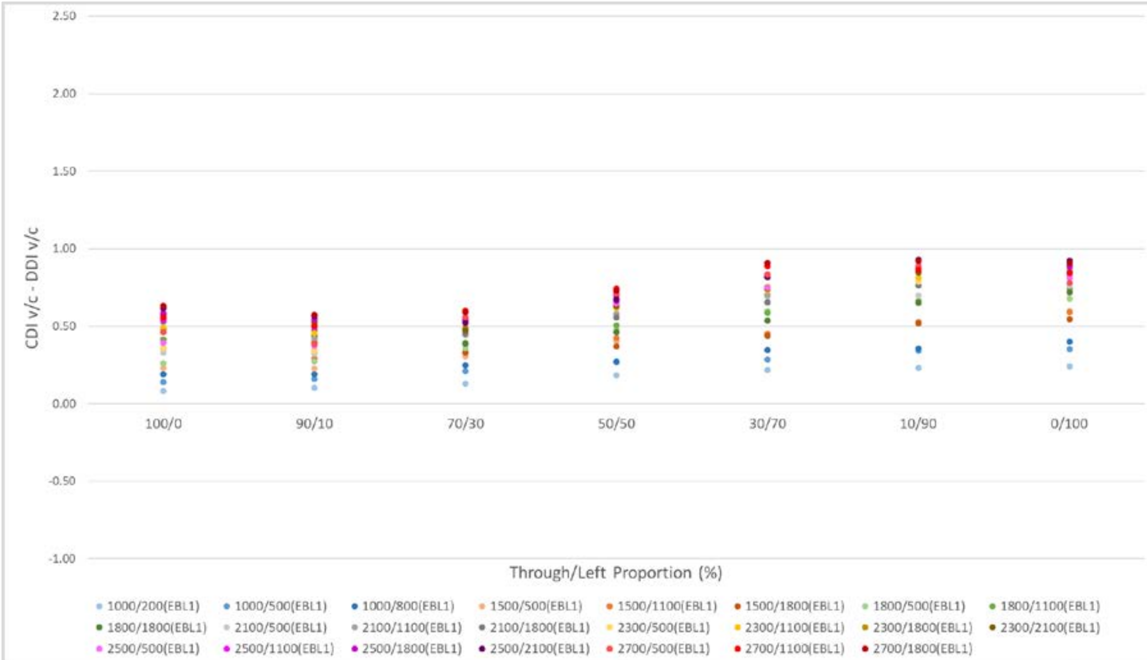


Figure D-12: Difference in v/c ratios between CDI and DDI on EBL1 at different traffic demands and through/left proportions for LC2

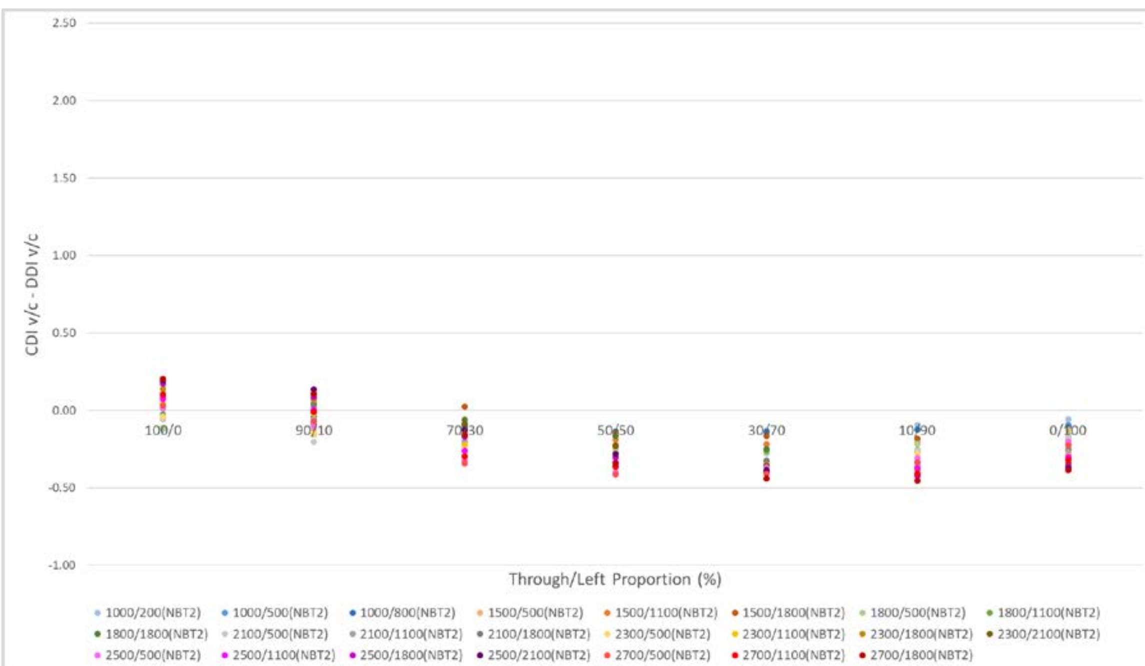


Figure D-13: Difference in v/c ratios between CDI and DDI on NBT2 at different traffic demands and through/left proportions for LC2

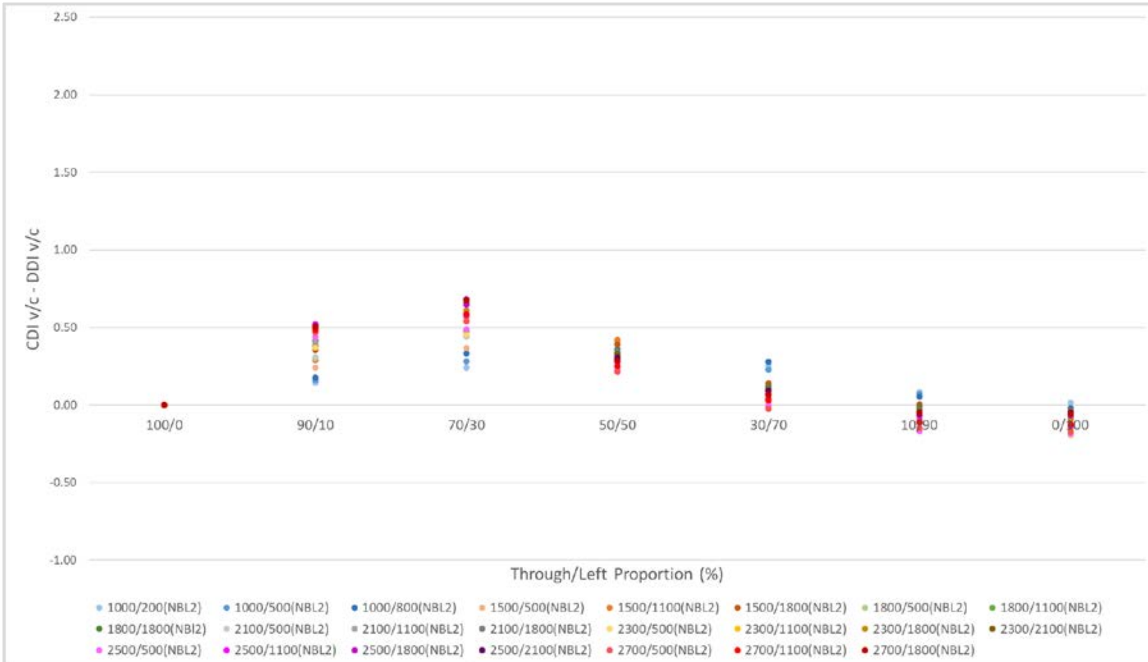


Figure D-14: Difference in v/c ratios between CDI and DDI on NBL2 at different traffic demands and through/left proportions for LC2

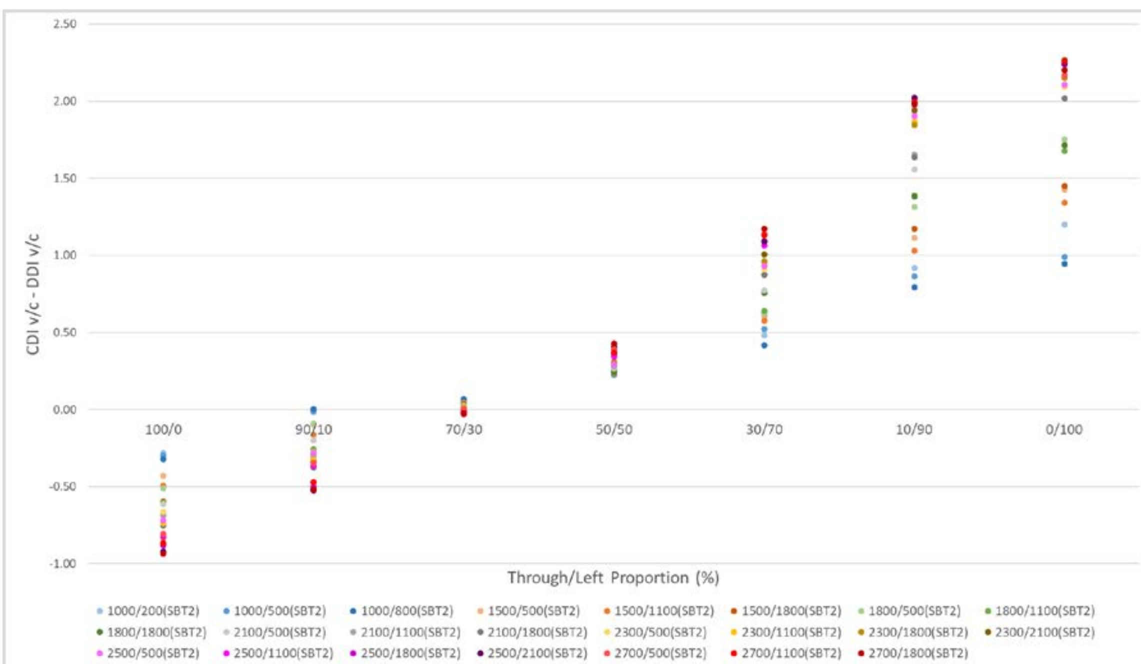


Figure D-15: Difference in v/c ratios between CDI and DDI on SBT2 at different traffic demands and through/left proportions for LC2

Figure D-16: Difference in v/c ratios between CDI and DDI on WBL2 at different traffic demands and through/left proportions for LC2

D.3 Lane Configuration 3

The following tables and plots present the difference in the CDI and DDI v/c ratios on different turning movements, traffic demands, and through/left proportions for LC3.

D.3.1 Color-Coded Tables of v/c ratios of CDIs and DDIs

Table D-11: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1000 vph (b) cross street demand of 1500 vph with different off-ramp demands and through/left proportions for LC3

(a)

		JC Volume 1000 vph					
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		200 vph		500 vph		800 vph	
100:0		0.28	0.60	0.33	0.67	0.35	0.68
90:10		0.39	0.51	0.47	0.57	0.48	0.57
70:30		0.39	0.39	0.44	0.41	0.48	0.44
50:50	NBT1	0.31	0.25	0.34	0.28	0.36	0.28
30:70		0.50	0.32	0.50	0.35	0.54	0.37
10:90		0.64	0.36	0.72	0.39	0.72	0.41
0:100		0.75	0.35	0.80	0.43	0.80	0.45
100:0		0.32	0.44	0.44	0.48	0.52	0.54
90:10		0.29	0.41	0.40	0.45	0.49	0.53
70:30		0.24	0.36	0.33	0.42	0.42	0.48
50:50	SBT1	0.18	0.30	0.25	0.35	0.33	0.43
30:70		0.12	0.22	0.19	0.29	0.26	0.36
10:90		0.06	0.14	0.12	0.23	0.18	0.32
0:100		0.03	0.09	0.09	0.17	0.15	0.26
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.11	0.02	0.14	0.02	0.17	0.02
70:30		0.25	0.06	0.27	0.06	0.30	0.06
50:50	SBL1	0.33	0.10	0.38	0.10	0.42	0.10
30:70		0.41	0.14	0.47	0.14	0.50	0.14
10:90		0.45	0.18	0.49	0.18	0.54	0.18
0:100		0.48	0.20	0.52	0.20	0.57	0.20
100:0		0.13	0.05	0.26	0.11	0.38	0.18
90:10		0.13	0.05	0.26	0.12	0.38	0.19
70:30		0.16	0.05	0.28	0.13	0.38	0.20
50:50	EBL1	0.18	0.06	0.31	0.14	0.42	0.22
30:70		0.18	0.07	0.35	0.15	0.45	0.23
10:90		0.21	0.08	0.34	0.17	0.46	0.26
0:100		0.21	0.09	0.38	0.17	0.50	0.26
100:0		0.32	0.42	0.44	0.46	0.52	0.51
90:10		0.29	0.40	0.40	0.44	0.48	0.49
70:30		0.24	0.34	0.33	0.41	0.42	0.46
50:50	NBT2	0.18	0.28	0.25	0.34	0.33	0.40
30:70		0.12	0.22	0.19	0.28	0.26	0.33
10:90		0.06	0.13	0.12	0.21	0.18	0.27
0:100		0.03	0.08	0.09	0.16	0.15	0.23
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.10	0.02	0.13	0.02	0.16	0.02
70:30		0.23	0.06	0.25	0.06	0.27	0.06
50:50	NBL2	0.33	0.10	0.36	0.10	0.38	0.10
30:70		0.41	0.14	0.44	0.14	0.47	0.14
10:90		0.45	0.18	0.49	0.18	0.51	0.18
0:100		0.46	0.20	0.52	0.20	0.55	0.20
100:0		0.28	0.63	0.33	0.71	0.35	0.75
90:10		0.40	0.54	0.50	0.60	0.49	0.64
70:30		0.41	0.41	0.47	0.44	0.50	0.47
50:50	SBT2	0.31	0.26	0.36	0.29	0.38	0.31
30:70		0.49	0.32	0.54	0.37	0.58	0.41
10:90		0.64	0.38	0.68	0.43	0.77	0.47
0:100		0.80	0.38	0.80	0.48	0.86	0.53
100:0		0.13	0.05	0.26	0.11	0.38	0.17
90:10		0.13	0.05	0.26	0.11	0.38	0.18
70:30		0.16	0.05	0.28	0.13	0.38	0.19
50:50	WBL2	0.18	0.06	0.31	0.13	0.42	0.20
30:70		0.19	0.07	0.35	0.14	0.45	0.21
10:90		0.21	0.07	0.38	0.16	0.46	0.23
0:100		0.21	0.08	0.38	0.16	0.50	0.23
100:0		0.28	0.49	0.39	0.53	0.48	0.58
90:10		0.26	0.44	0.36	0.49	0.45	0.53
70:30		0.30	0.36	0.32	0.41	0.40	0.45
50:50	Int v/c	0.30	0.27	0.35	0.31	0.36	0.36
30:70		0.40	0.27	0.45	0.31	0.50	0.36
10:90		0.48	0.27	0.53	0.31	0.58	0.36
0:100		0.53	0.26	0.58	0.31	0.63	0.36

(b)

		JC Volume 1500 vph					
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0		0.44	0.95	0.47	1.06	0.48	1.14
90:10		0.65	0.86	0.64	0.92	0.60	1.01
70:30		0.58	0.60	0.71	0.67	0.63	0.72
50:50	NBT1	0.45	0.41	0.53	0.43	0.55	0.47
30:70		0.71	0.50	0.77	0.55	0.86	0.60
10:90		0.95	0.56	1.08	0.64	1.16	0.68
0:100		1.17	0.60	1.20	0.68	1.35	0.75
100:0		0.53	0.62	0.69	0.62	0.83	0.73
90:10		0.52	0.60	0.67	0.69	0.81	0.70
70:30		0.41	0.55	0.61	0.65	0.76	0.68
50:50	SBT1	0.30	0.47	0.47	0.58	0.67	0.70
30:70		0.21	0.38	0.35	0.52	0.53	0.63
10:90		0.12	0.27	0.24	0.42	0.41	0.57
0:100		0.08	0.20	0.20	0.36	0.36	0.50
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.21	0.03	0.24	0.03	0.27	0.03
70:30		0.41	0.09	0.45	0.09	0.50	0.09
50:50	SBL1	0.50	0.15	0.56	0.15	0.63	0.15
30:70		0.59	0.21	0.64	0.21	0.70	0.21
10:90		0.65	0.27	0.61	0.27	0.64	0.27
0:100		0.58	0.30	0.56	0.30	0.58	0.30
100:0		0.33	0.11	0.59	0.22	0.78	0.36
90:10		0.31	0.11	0.54	0.23	0.77	0.34
70:30		0.35	0.13	0.52	0.26	0.72	0.35
50:50	EBL1	0.38	0.14	0.55	0.28	0.67	0.42
30:70		0.42	0.16	0.60	0.31	0.70	0.45
10:90		0.49	0.18	0.65	0.34	0.78	0.50
0:100		0.49	0.20	0.69	0.36	0.81	0.50
100:0		0.53	0.63	0.69	0.63	0.83	0.73
90:10		0.52	0.60	0.66	0.67	0.81	0.71
70:30		0.41	0.53	0.60	0.64	0.76	0.67
50:50	NBT2	0.30	0.47	0.45	0.56	0.67	0.66
30:70		0.21	0.36	0.35	0.49	0.53	0.59
10:90		0.12	0.26	0.24	0.38	0.41	0.49
0:100		0.08	0.18	0.20	0.31	0.36	0.44
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.19	0.03	0.22	0.03	0.26	0.03
70:30		0.38	0.09	0.44	0.09	0.48	0.09
50:50	NBL2	0.47	0.15	0.56	0.15	0.60	0.15
30:70		0.57	0.21	0.64	0.21	0.69	0.21
10:90		0.63	0.27	0.61	0.27	0.64	0.27
0:100		0.55	0.30	0.58	0.30	0.58	0.30
100:0		0.44	1.00	0.47	1.10	0.48	1.24
90:10		0.67	0.86	0.66	0.96	0.61	1.08
70:30		0.62	0.63	0.72	0.69	0.64	0.76
50:50	SBT2	0.47	0.41	0.50	0.45	0.57	0.53
30:70		0.73	0.53	0.77	0.58	0.85	0.66
10:90		0.99	0.59	1.08	0.71	1.17	0.81
0:100		1.12	0.63	1.26	0.79	1.35	0.90
100:0		0.34	0.11	0.59	0.21	0.78	0.35
90:10		0.31	0.11	0.54	0.23	0.78	0.33
70:30		0.35	0.12	0.52	0.25	0.72	0.34
50:50	WBL2	0.38	0.14	0.59	0.27	0.67	0.40
30:70		0.43	0.15	0.60	0.30	0.72	0.42
10:90		0.49	0.17	0.65	0.31	0.78	0.44
0:100		0.53	0.18	0.69	0.31	0.81	0.44
100:0		0.49	0.75	0.66	0.76	0.82	0.86
90:10		0.47	0.68	0.63	0.75	0.80	0.80
70:30		0.48	0.56	0.58	0.64	0.75	0.69
50:50	Int v/c	0.45	0.43	0.55	0.50	0.67	0.61
30:70		0.60	0.43	0.67	0.52	0.74	0.61
10:90		0.73	0.43	0.76	0.52	0.83	0.61
0:100		0.75	0.43	0.79	0.52	0.85	0.61

Table D-12: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at (a) cross street demand of 1800 vph (b) cross street demand of 2100 vph with different off-ramp demands and through/left proportions for LC3

(a)

JC Volume 1800 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0		0.51	1.15	0.52	1.25	0.54	1.35
90:10		0.75	1.01	0.69	1.10	0.64	1.19
70:30		0.70	0.71	0.77	0.77	0.72	0.86
50:50	NBT1	0.54	0.45	0.57	0.50	0.62	0.56
30:70		0.80	0.58	0.88	0.66	0.99	0.71
10:90		1.08	0.65	1.19	0.75	1.28	0.81
0:100		1.28	0.67	1.37	0.82	1.53	0.90
100:0		0.60	0.60	0.72	0.66	0.87	0.70
90:10		0.59	0.65	0.70	0.68	0.85	0.74
70:30		0.46	0.61	0.64	0.72	0.81	0.83
50:50	SBT1	0.34	0.54	0.48	0.62	0.68	0.74
30:70		0.22	0.44	0.36	0.56	0.54	0.65
10:90		0.12	0.31	0.24	0.44	0.39	0.58
0:100		0.08	0.22	0.18	0.36	0.33	0.50
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.24	0.04	0.28	0.04	0.34	0.04
70:30		0.45	0.11	0.50	0.11	0.60	0.11
50:50	SBL1	0.57	0.18	0.63	0.18	0.69	0.18
30:70		0.63	0.25	0.71	0.25	0.78	0.25
10:90		0.63	0.32	0.61	0.32	0.61	0.32
0:100		0.56	0.36	0.56	0.36	0.54	0.33
100:0		0.38	0.11	0.65	0.23	0.83	0.34
90:10		0.35	0.11	0.60	0.23	0.80	0.35
70:30		0.39	0.12	0.54	0.25	0.75	0.39
50:50	EBL1	0.42	0.14	0.60	0.27	0.71	0.41
30:70		0.46	0.16	0.66	0.31	0.78	0.44
10:90		0.56	0.20	0.72	0.35	0.84	0.50
0:100		0.59	0.22	0.76	0.36	0.85	0.50
100:0		0.60	0.61	0.72	0.67	0.88	0.71
90:10		0.59	0.65	0.70	0.68	0.85	0.74
70:30		0.46	0.60	0.64	0.70	0.81	0.81
50:50	NBT2	0.34	0.52	0.48	0.60	0.68	0.72
30:70		0.22	0.43	0.35	0.54	0.53	0.63
10:90		0.12	0.29	0.24	0.43	0.39	0.52
0:100		0.08	0.20	0.18	0.34	0.33	0.45
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.26	0.04	0.26	0.04	0.32	0.04
70:30		0.45	0.11	0.48	0.11	0.58	0.11
50:50	NBL2	0.55	0.18	0.63	0.18	0.68	0.18
30:70		0.63	0.25	0.70	0.25	0.77	0.25
10:90		0.63	0.32	0.61	0.32	0.61	0.32
0:100		0.56	0.36	0.56	0.36	0.54	0.36
100:0		0.51	1.20	0.52	1.31	0.54	1.44
90:10		0.74	1.00	0.70	1.11	0.65	1.23
70:30		0.70	0.74	0.78	0.80	0.74	0.89
50:50	SBT2	0.55	0.47	0.57	0.53	0.63	0.58
30:70		0.80	0.60	0.90	0.70	0.99	0.74
10:90		1.08	0.68	1.19	0.78	1.32	0.93
0:100		1.27	0.72	1.37	0.87	1.53	1.03
100:0		0.38	0.11	0.65	0.22	0.82	0.33
90:10		0.35	0.11	0.60	0.23	0.80	0.34
70:30		0.39	0.12	0.54	0.25	0.75	0.38
50:50	WBL2	0.43	0.13	0.60	0.26	0.72	0.40
30:70		0.47	0.16	0.66	0.30	0.78	0.43
10:90		0.56	0.18	0.72	0.34	0.84	0.45
0:100		0.59	0.20	0.76	0.34	0.85	0.45
100:0		0.56	0.80	0.71	0.86	0.86	0.90
90:10		0.53	0.77	0.68	0.81	0.83	0.87
70:30		0.56	0.64	0.61	0.72	0.79	0.82
50:50	Int v/c	0.53	0.49	0.60	0.56	0.69	0.66
30:70		0.67	0.50	0.75	0.59	0.84	0.66
10:90		0.77	0.50	0.81	0.59	0.87	0.68
0:100		0.80	0.50	0.84	0.59	0.88	0.68

(b)

JC Volume 2100 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0		0.57	1.33	0.58	1.44	0.60	1.52
90:10		0.72	1.15	0.75	1.22	0.69	1.31
70:30		0.77	0.78	0.82	0.87	0.82	0.93
50:50	NBT1	0.57	0.51	0.63	0.57	0.69	0.63
30:70		0.85	0.65	0.93	0.71	1.03	0.76
10:90		1.23	0.73	1.30	0.82	1.45	0.91
0:100		1.42	0.74	1.53	0.91	1.68	1.01
100:0		0.65	0.60	0.77	0.64	0.92	0.71
90:10		0.60	0.65	0.75	0.69	0.89	0.74
70:30		0.51	0.70	0.67	0.78	0.83	0.84
50:50	SBT1	0.36	0.60	0.51	0.67	0.69	0.79
30:70		0.24	0.47	0.36	0.61	0.52	0.72
10:90		0.13	0.35	0.23	0.50	0.38	0.58
0:100		0.07	0.22	0.18	0.38	0.32	0.52
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.29	0.04	0.32	0.04	0.40	0.04
70:30		0.53	0.13	0.55	0.13	0.58	0.13
50:50	SBL1	0.64	0.21	0.69	0.21	0.75	0.21
30:70		0.72	0.29	0.75	0.29	0.76	0.29
10:90		0.60	0.38	0.60	0.38	0.61	0.38
0:100		0.54	0.42	0.53	0.42	0.54	0.37
100:0		0.44	0.11	0.69	0.22	0.88	0.34
90:10		0.40	0.11	0.65	0.23	0.84	0.34
70:30		0.45	0.12	0.57	0.25	0.78	0.37
50:50	EBL1	0.49	0.14	0.65	0.27	0.77	0.41
30:70		0.56	0.16	0.72	0.32	0.84	0.46
10:90		0.63	0.21	0.78	0.38	0.88	0.49
0:100		0.66	0.22	0.81	0.38	0.92	0.52
100:0		0.65	0.60	0.77	0.64	0.92	0.71
90:10		0.60	0.65	0.75	0.70	0.89	0.74
70:30		0.51	0.68	0.66	0.77	0.83	0.82
50:50	NBT2	0.36	0.58	0.50	0.67	0.69	0.77
30:70		0.24	0.46	0.36	0.59	0.52	0.68
10:90		0.13	0.33	0.23	0.47	0.38	0.55
0:100		0.07	0.21	0.18	0.36	0.31	0.49
100:0		0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.28	0.04	0.30	0.04	0.39	0.04
70:30		0.53	0.13	0.55	0.13	0.63	0.13
50:50	NBL2	0.61	0.21	0.67	0.21	0.75	0.21
30:70		0.70	0.29	0.75	0.29	0.76	0.29
10:90		0.60	0.38	0.60	0.38	0.60	0.38
0:100		0.55	0.42	0.54	0.42	0.53	0.40
100:0		0.57	1.35	0.58	1.48	0.60	1.59
90:10		0.73	1.15	0.76	1.26	0.69	1.37
70:30		0.77	0.81	0.79	0.90	0.78	0.98
50:50	SBT2	0.59	0.53	0.64	0.57	0.68	0.65
30:70		0.88	0.67	0.93	0.74	1.03	0.82
10:90		1.22	0.76	1.32	0.86	1.42	0.98
0:100		1.45	0.76	1.56	0.95	1.68	1.08
100:0		0.44	0.10	0.69	0.21	0.88	0.33
90:10		0.40	0.11	0.65	0.22	0.84	0.34
70:30		0.45	0.12	0.60	0.24	0.78	0.36
50:50	WBL2	0.49	0.13	0.66	0.26	0.78	0.40
30:70		0.56	0.15	0.72	0.31	0.84	0.44
10:90		0.64	0.20	0.79	0.36	0.90	0.46
0:100		0.66	0.21	0.81	0.36	0.94	0.49
100:0		0.62	0.85	0.75	0.89	0.91	0.95
90:10		0.57	0.82	0.73	0.87	0.87	0.92
70:30		0.63	0.72	0.64	0.81	0.82	0.87
50:50	Int v/c	0.58	0.54	0.66	0.62	0.72	0.72
30:70		0.75	0.56	0.81	0.64	0.87	0.73
10:90		0.82	0.57	0.86	0.66	0.92	0.73
0:100		0.85	0.56	0.89	0.66	0.95	0.74

Table D-13: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2300 vph with different off-ramp demands and through/left proportions LC3

JC Volume 2300 vph									
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0	NBT1	0.59	1.45	0.62	1.56	0.65	1.38	0.67	1.73
90:10		0.73	1.22	0.77	1.32	0.74	1.08	0.75	1.49
70:30		0.82	0.85	0.87	0.92	0.82	1.03	0.80	1.05
50:50		0.61	0.54	0.65	0.59	0.71	0.68	0.74	0.70
30:70		0.91	0.69	1.02	0.77	1.10	0.86	1.12	0.88
10:90		1.32	0.75	1.41	0.90	1.55	0.97	1.62	1.00
0:100		1.53	0.79	1.62	0.95	1.80	1.07	1.84	1.12
100:0	SBT1	0.67	0.60	0.81	0.64	0.96	0.78	1.05	0.74
90:10		0.64	0.66	0.78	0.68	0.92	0.86	1.00	0.77
70:30		0.54	0.74	0.70	0.80	0.86	0.83	0.90	0.84
50:50		0.38	0.63	0.52	0.72	0.71	0.78	0.80	0.85
30:70		0.24	0.52	0.37	0.64	0.53	0.73	0.60	0.75
10:90		0.13	0.36	0.23	0.51	0.38	0.61	0.43	0.65
0:100		0.07	0.26	0.17	0.38	0.31	0.51	0.34	0.55
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.34	0.05	0.35	0.05	0.43	0.05	0.44	0.05
70:30		0.54	0.14	0.60	0.14	0.68	0.14	0.64	0.14
50:50		0.66	0.23	0.74	0.23	0.83	0.23	0.84	0.23
30:70		0.73	0.32	0.75	0.32	0.76	0.32	0.76	0.32
10:90		0.60	0.41	0.59	0.41	0.59	0.38	0.60	0.37
0:100		0.52	0.46	0.53	0.46	0.53	0.38	0.54	0.37
100:0	EBL1	0.47	0.10	0.72	0.21	0.92	0.36	0.98	0.38
90:10		0.42	0.11	0.69	0.22	0.88	0.40	0.95	0.39
70:30		0.42	0.12	0.60	0.24	0.79	0.36	0.88	0.41
50:50		0.50	0.14	0.69	0.27	0.84	0.39	0.85	0.45
30:70		0.60	0.16	0.75	0.32	0.86	0.45	0.91	0.49
10:90		0.67	0.21	0.83	0.38	0.94	0.51	0.98	0.55
0:100		0.71	0.26	0.88	0.38	0.99	0.51	1.05	0.55
100:0	NBT2	0.67	0.60	0.81	0.64	0.96	0.79	1.05	0.74
90:10		0.64	0.66	0.78	0.69	0.92	0.88	0.99	0.77
70:30		0.52	0.72	0.68	0.79	0.86	0.83	0.90	0.84
50:50		0.38	0.62	0.52	0.70	0.71	0.77	0.80	0.84
30:70		0.24	0.50	0.37	0.61	0.53	0.73	0.60	0.74
10:90		0.13	0.34	0.23	0.48	0.38	0.58	0.44	0.62
0:100		0.07	0.22	0.17	0.36	0.31	0.48	0.34	0.53
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.32	0.05	0.33	0.05	0.41	0.05	0.43	0.05
70:30		0.55	0.14	0.60	0.14	0.66	0.14	0.63	0.14
50:50		0.66	0.23	0.71	0.23	0.80	0.23	0.82	0.23
30:70		0.73	0.32	0.75	0.32	0.76	0.32	0.76	0.32
10:90		0.60	0.41	0.59	0.41	0.59	0.41	0.59	0.39
0:100		0.52	0.46	0.54	0.46	0.53	0.41	0.54	0.39
100:0	SBT2	0.59	1.45	0.62	1.56	0.65	1.73	0.67	1.80
90:10		0.74	1.25	0.78	1.35	0.74	1.49	0.75	1.55
70:30		0.77	0.88	0.83	0.94	0.83	1.04	0.80	1.09
50:50		0.61	0.56	0.67	0.61	0.74	0.70	0.77	0.71
30:70		0.90	0.72	1.02	0.81	1.10	0.86	1.14	0.89
10:90		1.31	0.78	1.41	0.94	1.55	1.03	1.59	1.07
0:100		1.55	0.85	1.66	0.99	1.84	1.14	1.88	1.19
100:0	WBL2	0.47	0.10	0.72	0.21	0.92	0.33	0.98	0.38
90:10		0.42	0.11	0.69	0.22	0.88	0.33	0.96	0.38
70:30		0.47	0.12	0.64	0.24	0.80	0.36	0.88	0.40
50:50		0.50	0.13	0.69	0.26	0.84	0.38	0.85	0.45
30:70		0.61	0.16	0.75	0.31	0.86	0.45	0.91	0.49
10:90		0.68	0.20	0.83	0.36	0.94	0.48	1.01	0.53
0:100		0.72	0.22	0.88	0.36	0.99	0.48	1.05	0.53
100:0	Int v/c	0.64	0.88	0.79	0.92	0.95	1.05	1.03	1.02
90:10		0.60	0.87	0.76	0.90	0.91	1.05	0.98	0.98
70:30		0.65	0.78	0.72	0.84	0.84	0.89	0.89	0.92
50:50		0.61	0.58	0.69	0.66	0.79	0.74	0.81	0.79
30:70		0.79	0.60	0.84	0.69	0.89	0.77	0.92	0.79
10:90		0.86	0.60	0.89	0.71	0.96	0.77	0.99	0.80
0:100		0.87	0.62	0.93	0.69	0.99	0.77	1.03	0.80

Table D-14: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2500 vph with different off-ramp demands and through/left proportions for LC3

JC Volume 2500 vph									
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph		2100 vph	
100:0	NBT1	0.64	1.55	0.66	1.67	0.70	1.80	0.71	1.84
90:10		0.74	1.33	0.81	1.42	0.79	1.56	0.81	1.59
70:30		0.84	0.92	0.88	1.00	0.85	1.09	0.89	1.13
50:50		0.63	0.58	0.70	0.64	0.76	0.71	0.78	0.73
30:70		0.97	0.72	1.07	0.82	1.14	0.88	1.21	0.90
10:90		1.41	0.86	1.50	0.93	1.62	1.02	1.72	1.04
0:100		1.61	0.86	1.73	1.00	1.91	1.13	2.00	1.14
100:0	SBT1	0.72	0.59	0.84	0.64	1.01	0.72	1.06	0.75
90:10		0.66	0.64	0.81	0.68	0.96	0.75	1.03	0.78
70:30		0.56	0.77	0.71	0.80	0.87	0.84	0.94	0.87
50:50		0.39	0.67	0.54	0.75	0.71	0.84	0.80	0.86
30:70		0.25	0.55	0.37	0.65	0.53	0.75	0.61	0.79
10:90		0.13	0.38	0.23	0.51	0.36	0.64	0.41	0.67
0:100		0.07	0.26	0.17	0.39	0.27	0.53	0.32	0.58
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.38	0.05	0.38	0.05	0.45	0.05	0.45	0.05
70:30		0.60	0.15	0.63	0.15	0.70	0.15	0.65	0.15
50:50		0.70	0.25	0.78	0.25	0.81	0.25	0.85	0.25
30:70		0.77	0.35	0.75	0.35	0.76	0.35	0.75	0.35
10:90		0.59	0.45	0.60	0.45	0.60	0.39	0.59	0.39
0:100		0.53	0.50	0.54	0.46	0.54	0.39	0.53	0.38
100:0	EBL1	0.48	0.10	0.77	0.21	0.94	0.33	1.03	0.39
90:10		0.45	0.11	0.71	0.22	0.91	0.34	0.98	0.39
70:30		0.47	0.12	0.65	0.24	0.82	0.36	0.89	0.41
50:50		0.56	0.13	0.73	0.26	0.81	0.40	0.86	0.44
30:70		0.66	0.16	0.80	0.31	0.91	0.45	0.95	0.50
10:90		0.72	0.21	0.90	0.38	1.01	0.52	1.05	0.56
0:100		0.80	0.26	0.95	0.39	1.07	0.53	1.10	0.58
100:0	NBT2	0.72	0.59	0.84	0.64	1.01	0.72	1.06	0.76
90:10		0.66	0.64	0.81	0.69	0.96	0.75	1.03	0.78
70:30		0.56	0.76	0.71	0.81	0.87	0.84	0.94	0.87
50:50		0.39	0.65	0.54	0.73	0.71	0.83	0.80	0.85
30:70		0.25	0.53	0.37	0.65	0.53	0.73	0.61	0.76
10:90		0.13	0.38	0.23	0.49	0.36	0.60	0.41	0.64
0:100		0.07	0.22	0.17	0.38	0.27	0.49	0.32	0.54
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.36	0.05	0.36	0.05	0.43	0.05	0.44	0.05
70:30		0.60	0.15	0.63	0.15	0.68	0.15	0.64	0.15
50:50		0.68	0.25	0.77	0.25	0.81	0.25	0.85	0.25
30:70		0.77	0.35	0.75	0.35	0.76	0.35	0.75	0.35
10:90		0.59	0.45	0.60	0.45	0.60	0.42	0.59	0.41
0:100		0.54	0.50	0.54	0.48	0.54	0.42	0.53	0.42
100:0	SBT2	0.64	1.55	0.66	1.70	0.70	1.84	0.71	1.91
90:10		0.75	1.36	0.82	1.45	0.79	1.59	0.81	1.65
70:30		0.84	0.93	0.88	1.02	0.86	1.11	0.89	1.15
50:50		0.64	0.59	0.71	0.65	0.76	0.72	0.78	0.74
30:70		0.96	0.74	1.07	0.82	1.17	0.90	1.21	0.95
10:90		1.41	0.86	1.50	0.96	1.65	1.09	1.72	1.09
0:100		1.64	0.93	1.76	1.03	1.91	1.21	2.00	1.25
100:0	WBL2	0.49	0.10	0.77	0.21	0.94	0.33	1.03	0.38
90:10		0.45	0.10	0.72	0.22	0.91	0.34	0.98	0.39
70:30		0.47	0.12	0.65	0.24	0.82	0.36	0.89	0.41
50:50		0.56	0.13	0.73	0.26	0.82	0.39	0.86	0.44
30:70		0.66	0.16	0.80	0.31	0.91	0.44	0.95	0.49
10:90		0.72	0.21	0.90	0.36	1.01	0.49	1.05	0.54
0:100		0.80	0.22	0.95	0.38	1.07	0.49	1.10	0.54
100:0	Int v/c	0.69	0.91	0.83	0.97	0.99	1.03	1.05	1.07
90:10		0.63	0.89	0.79	0.93	0.94	0.99	1.02	1.03
70:30		0.70	0.82	0.75	0.88	0.86	0.92	0.92	0.95
50:50		0.65	0.62	0.74	0.69	0.79	0.78	0.82	0.81
30:70		0.83	0.64	0.87	0.72	0.93	0.80	0.95	0.83
10:90		0.89	0.67	0.94	0.74	1.01	0.82	1.03	0.84
0:100		0.92	0.67	0.98	0.74	1.04	0.82	1.07	0.85

Table D-15: Colored-coded tables of the CDI and DDI turning movement and interchange v/c ratios at cross street demand of 2700 vph with different off-ramp demands and through/left proportions for LC3

JC Volume 2700 vph							
Proportion	Approach	CDI	DDI	CDI	DDI	CDI	DDI
		500 vph		1100 vph		1800 vph	
100:0	NBT1	0.67	1.65	0.70	1.77	0.74	1.91
90:10		0.77	1.40	0.85	1.51	0.84	1.65
70:30		0.85	0.96	0.90	1.05	0.89	1.15
50:50		0.66	0.61	0.70	0.68	0.78	0.74
30:70		1.02	0.80	1.12	0.85	1.24	0.93
10:90		1.48	0.90	1.59	0.97	1.75	1.06
0:100		1.74	0.93	1.87	1.04	2.03	1.18
100:0	SBT1	0.74	0.59	0.88	0.66	1.05	0.73
90:10		0.69	0.64	0.84	0.70	0.99	0.76
70:30		0.58	0.80	0.73	0.81	0.89	0.85
50:50		0.41	0.71	0.53	0.79	0.72	0.86
30:70		0.26	0.60	0.38	0.70	0.54	0.79
10:90		0.13	0.42	0.24	0.55	0.34	0.67
0:100		0.07	0.26	0.17	0.46	0.25	0.54
100:0	SBL1	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.40	0.05	0.40	0.05	0.46	0.05
70:30		0.63	0.16	0.65	0.16	0.72	0.16
50:50		0.72	0.27	0.77	0.27	0.86	0.27
30:70		0.75	0.38	0.75	0.38	0.76	0.38
10:90		0.60	0.49	0.59	0.46	0.59	0.42
0:100		0.54	0.54	0.53	0.47	0.54	0.42
100:0	EBL1	0.57	0.10	0.80	0.21	0.99	0.34
90:10		0.49	0.10	0.76	0.22	0.94	0.34
70:30		0.49	0.11	0.65	0.23	0.85	0.36
50:50		0.57	0.13	0.73	0.27	0.87	0.39
30:70		0.69	0.17	0.83	0.32	0.94	0.46
10:90		0.82	0.22	0.95	0.39	1.07	0.54
0:100		0.87	0.26	0.99	0.46	1.13	0.54
100:0	NBT2	0.74	0.60	0.88	0.66	1.05	0.74
90:10		0.69	0.65	0.84	0.70	0.99	0.76
70:30		0.58	0.79	0.73	0.81	0.89	0.85
50:50		0.40	0.69	0.53	0.77	0.72	0.86
30:70		0.26	0.60	0.38	0.68	0.54	0.77
10:90		0.13	0.39	0.24	0.52	0.34	0.65
0:100		0.07	0.24	0.17	0.42	0.25	0.53
100:0	NBL2	0.00	0.00	0.00	0.00	0.00	0.00
90:10		0.39	0.05	0.39	0.05	0.45	0.05
70:30		0.60	0.16	0.65	0.16	0.70	0.16
50:50		0.71	0.27	0.76	0.27	0.86	0.27
30:70		0.75	0.38	0.74	0.38	0.75	0.38
10:90		0.60	0.49	0.59	0.49	0.59	0.43
0:100		0.54	0.54	0.54	0.49	0.54	0.43
100:0	SBT2	0.67	1.68	0.70	1.80	0.74	1.94
90:10		0.78	1.42	0.85	1.53	0.85	1.68
70:30		0.88	0.98	0.90	1.06	0.90	1.17
50:50		0.67	0.63	0.71	0.69	0.78	0.75
30:70		1.04	0.80	1.12	0.88	1.22	0.95
10:90		1.48	0.93	1.62	1.01	1.75	1.10
0:100		1.74	0.96	1.91	1.10	2.03	1.22
100:0	WBL2	0.57	0.10	0.80	0.21	0.99	0.33
90:10		0.49	0.10	0.76	0.22	0.94	0.34
70:30		0.49	0.11	0.65	0.23	0.85	0.36
50:50		0.60	0.13	0.73	0.26	0.87	0.39
30:70		0.70	0.17	0.85	0.31	0.96	0.45
10:90		0.82	0.21	0.95	0.38	1.07	0.53
0:100		0.87	0.24	0.99	0.42	1.13	0.53
100:0	Int v/c	0.72	0.96	0.86	1.01	1.04	1.08
90:10		0.66	0.92	0.82	0.97	0.98	1.04
70:30		0.73	0.86	0.77	0.90	0.88	0.96
50:50		0.68	0.65	0.73	0.73	0.83	0.81
30:70		0.86	0.70	0.90	0.76	0.96	0.84
10:90		0.93	0.72	0.98	0.78	1.04	0.86
0:100		0.96	0.72	1.02	0.81	1.09	0.86

D.3.2 Plots of difference between CDI and DDI v/c ratios

Figure D-17: Difference in v/c ratios between CDI and DDI on NBT1 at different traffic demands and through/left proportions for LC3

Figure D-18: Difference in v/c ratios between CDI and DDI on SBT1 at different traffic demands and through/left proportions for LC3

Figure D-19: Difference in v/c ratios between CDI and DDI on SBL1 at different traffic demands and through/left proportions for LC3

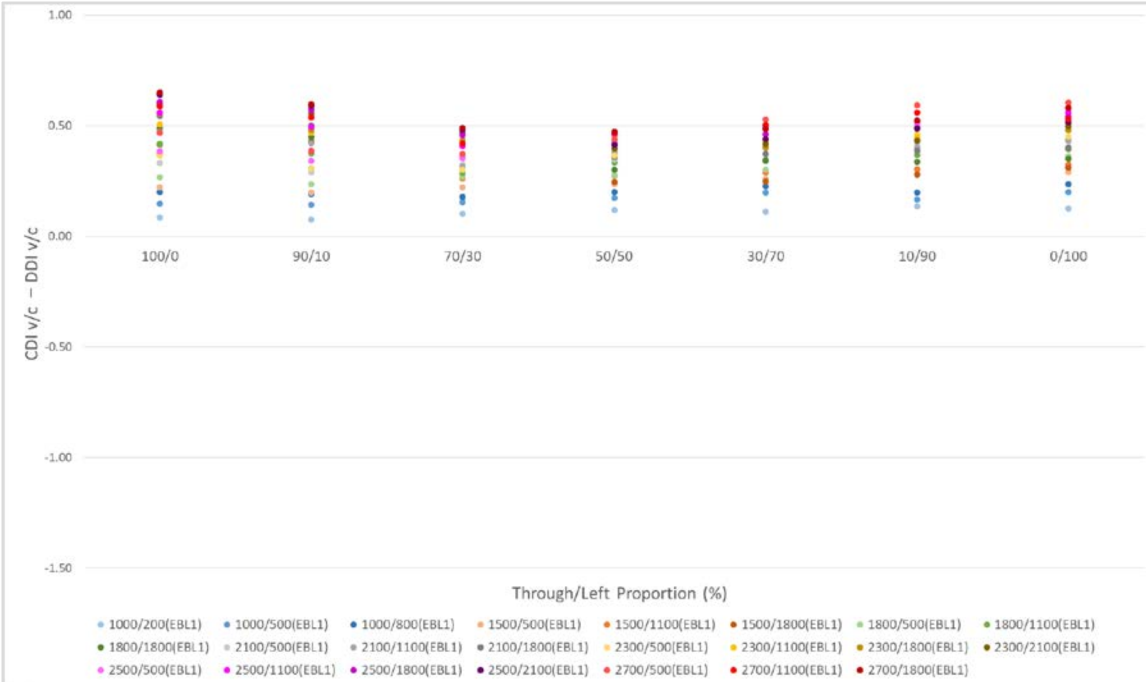


Figure D-20: Difference in v/c ratios between CDI and DDI on EBL1 at different traffic demands and through/left proportions for LC3

Figure D-21: Difference in v/c ratios between CDI and DDI on NBT2 at different traffic demands and through/left proportions for LC3

Figure D-22: Difference in v/c ratios between CDI and DDI on NBL2 at different traffic demands and through/left proportions for LC3

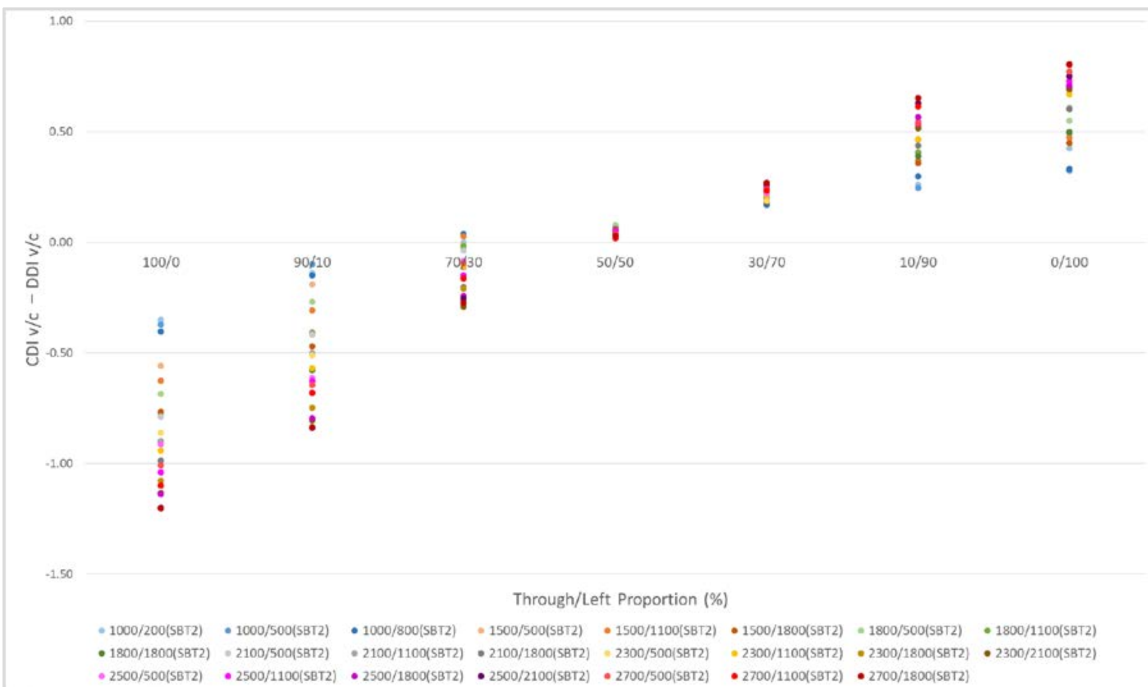


Figure D-23: Difference in v/c ratios between CDI and DDI on SBT2 at different traffic demands and through/left proportions for LC3

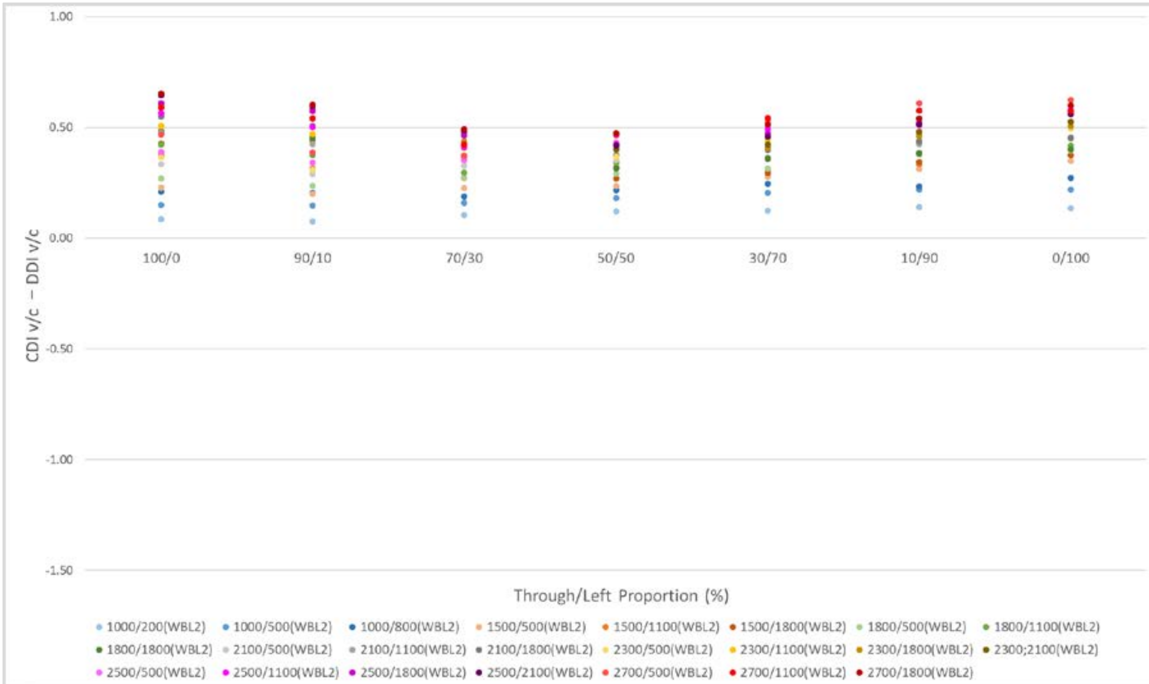


Figure D-24: Difference in v/c ratios between CDI and DDI on WBL2 at different traffic demands and through/left proportions for LC3

APPENDIX E. MICROSCOPIC SIMULATION STUDY RESULTS

This appendix provides resulted plots of average delay per vehicle and throughput at different through/left proportions from the VISSIM simulation study. Each plot illustrates the performance measures of individual turning movements. Numbers in the legend represent different off-ramp demands tested in the simulation.

E.1 Lane Configuration 1

E.1.1 Cross street Demand: 1500 vph

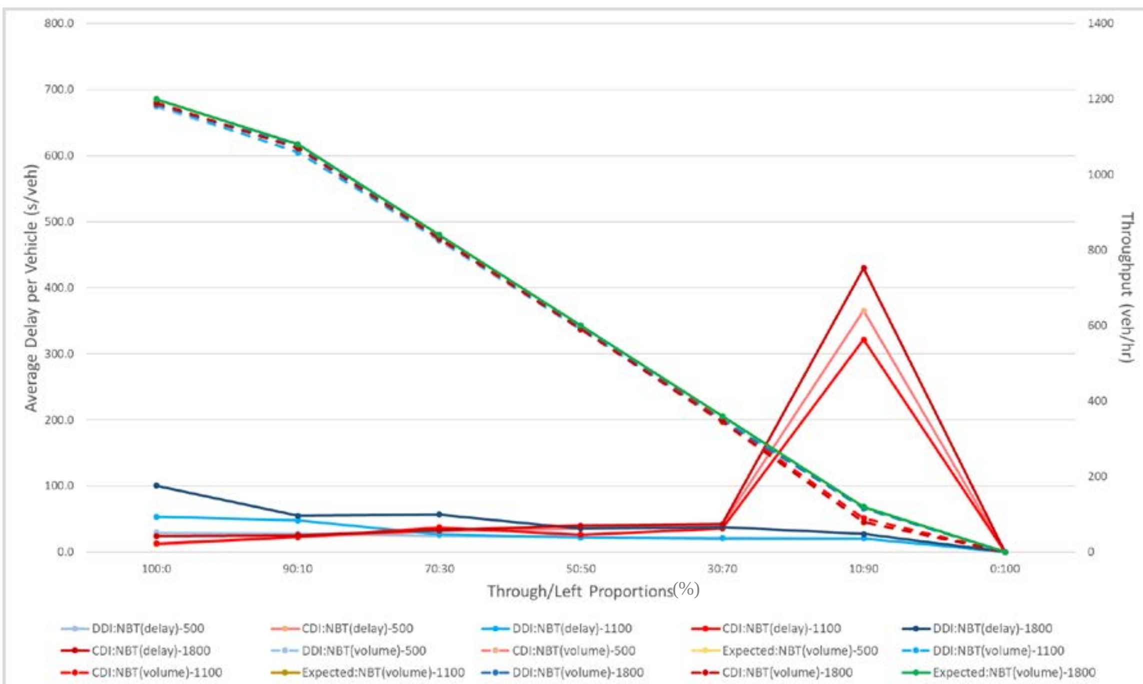


Figure E-1: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

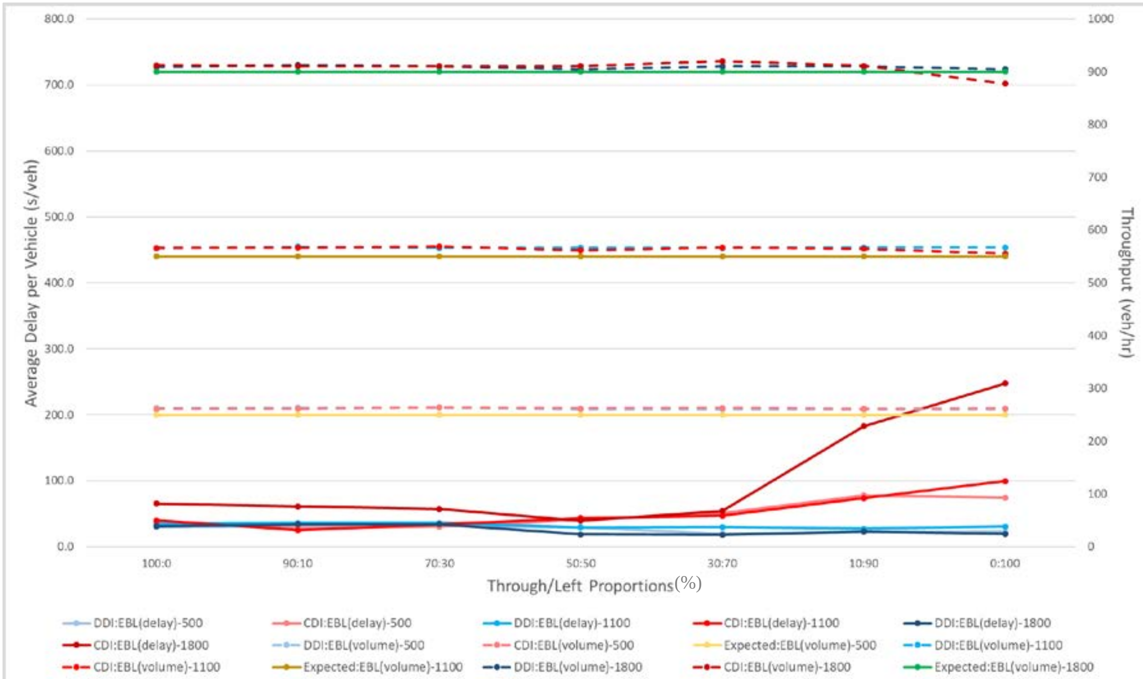


Figure E-2: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

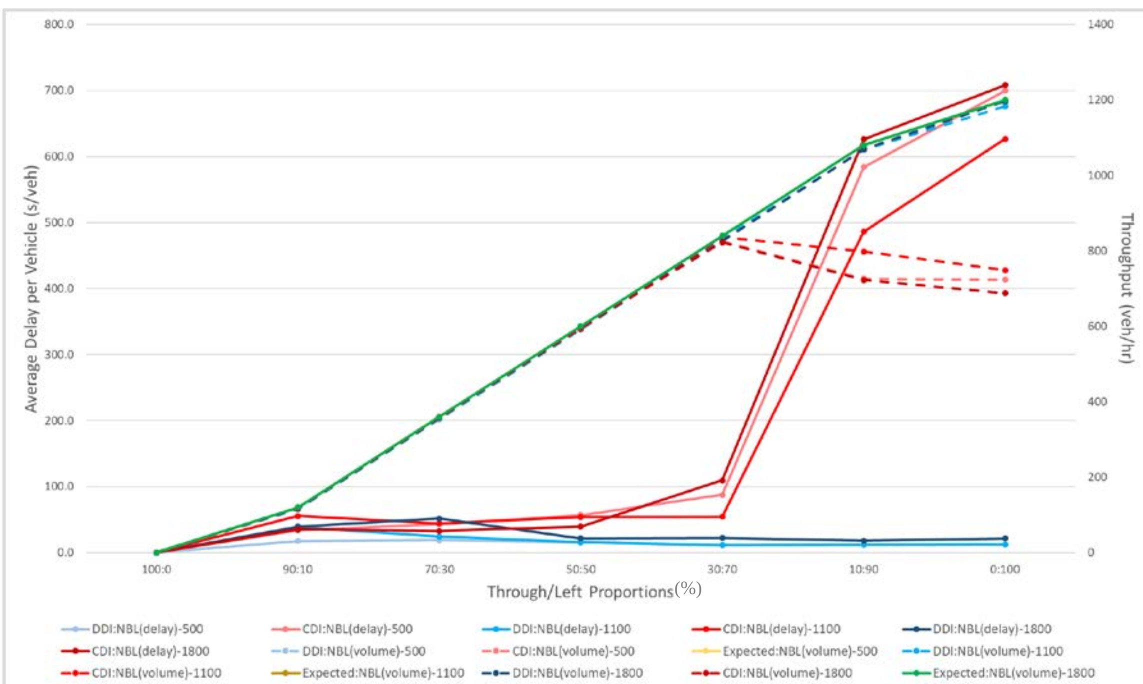


Figure E-3: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

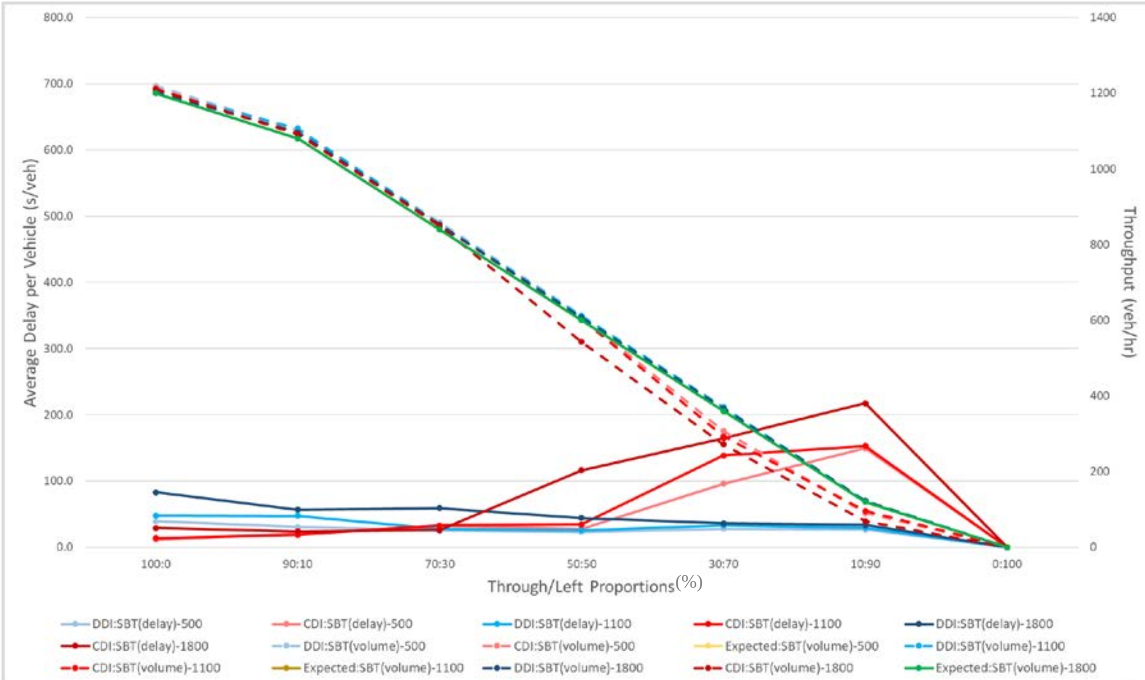


Figure E-4: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

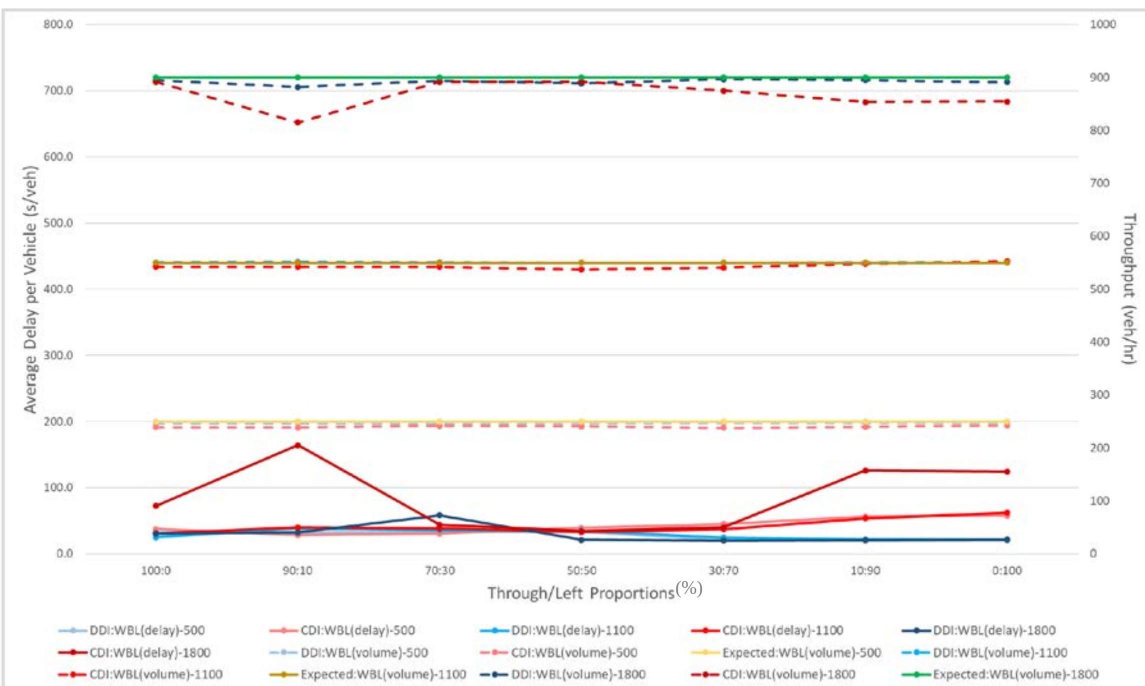


Figure E-5: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

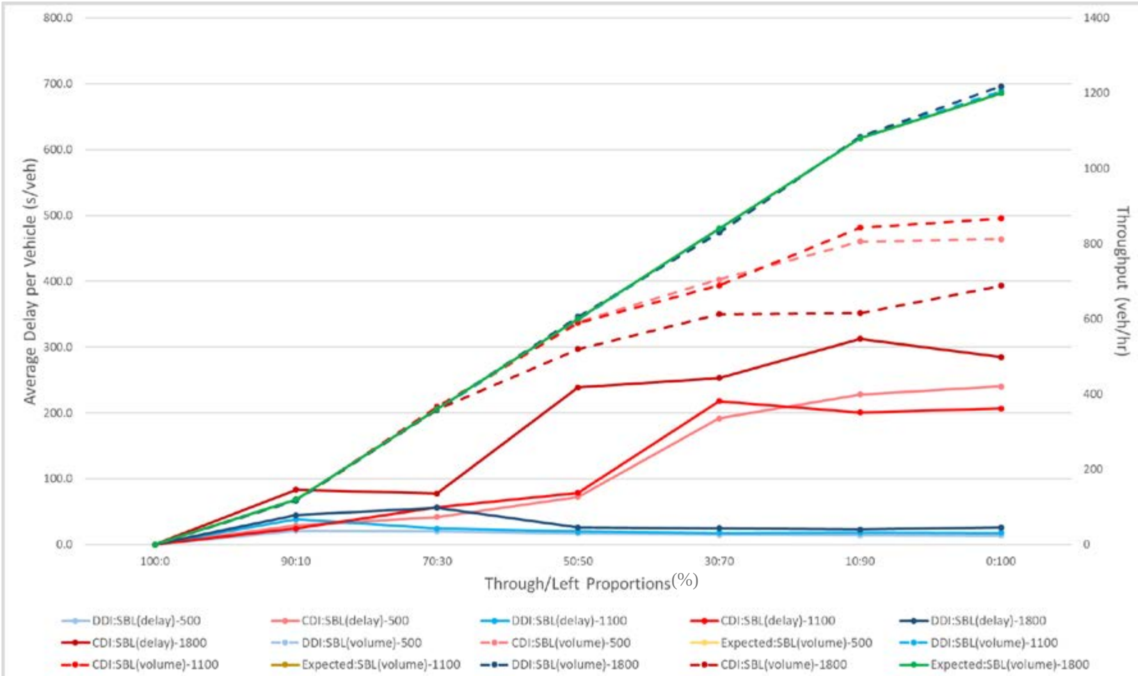


Figure E-6: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC1

E.1.2 Cross street Demand: 2100 vph

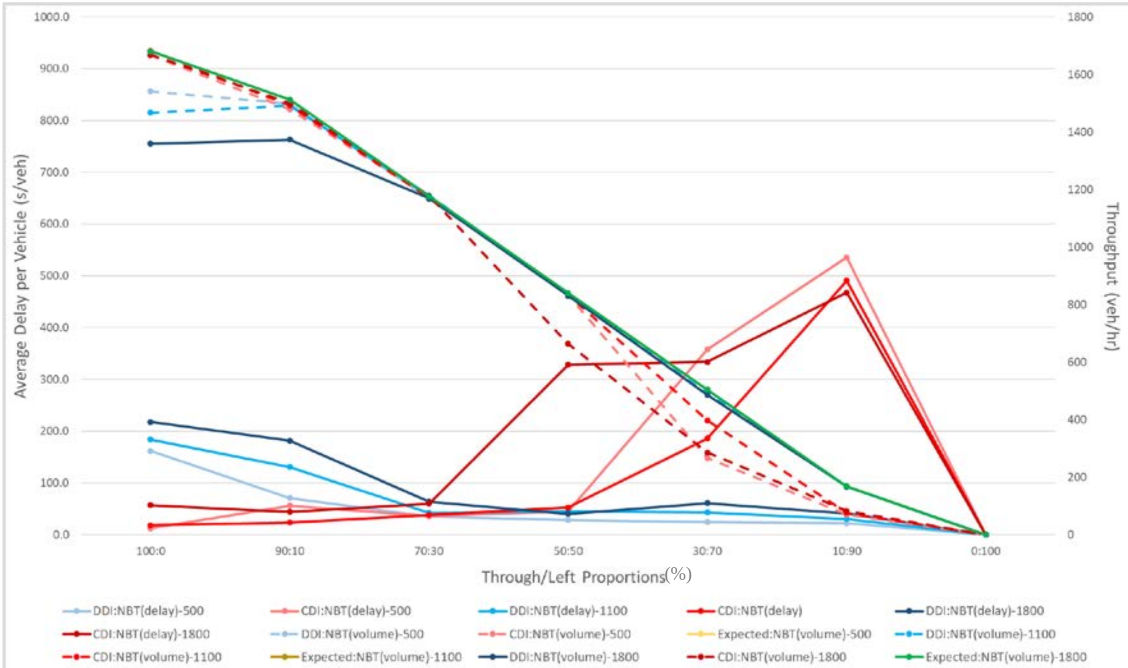


Figure E-7: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

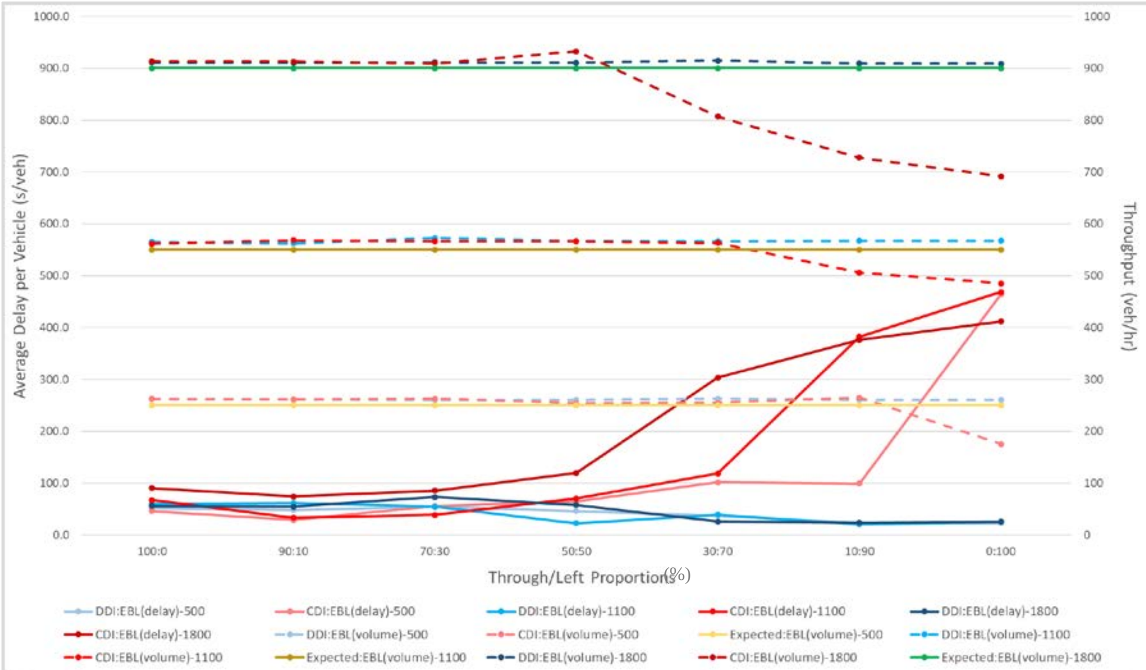


Figure E-8: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

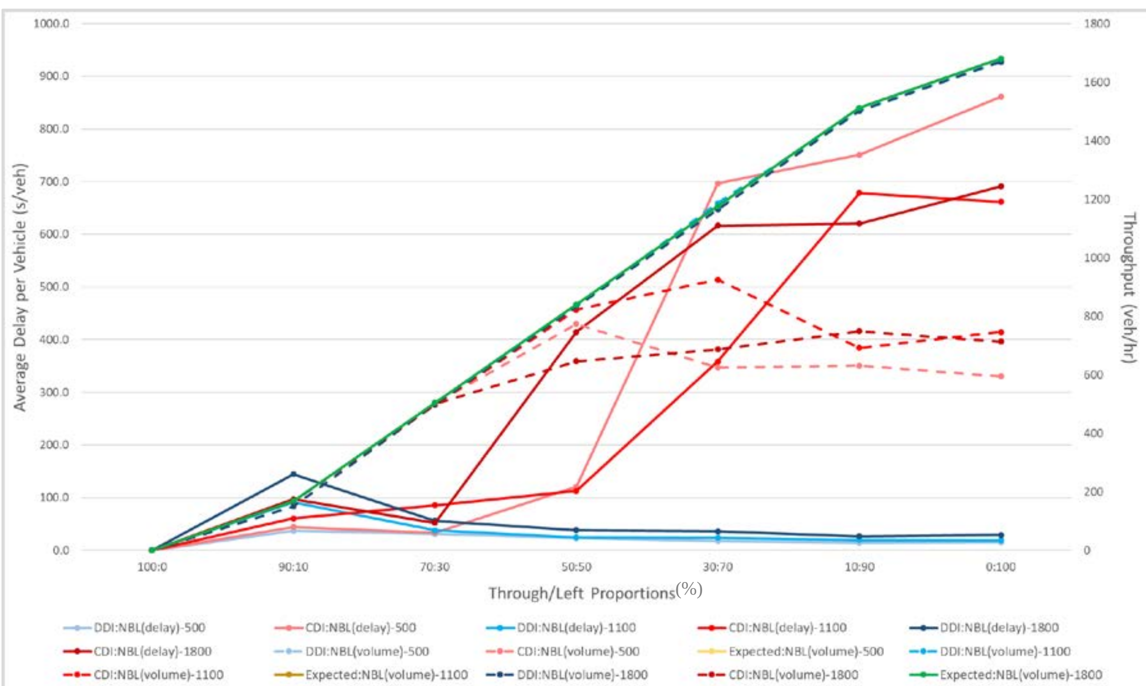


Figure E-9: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

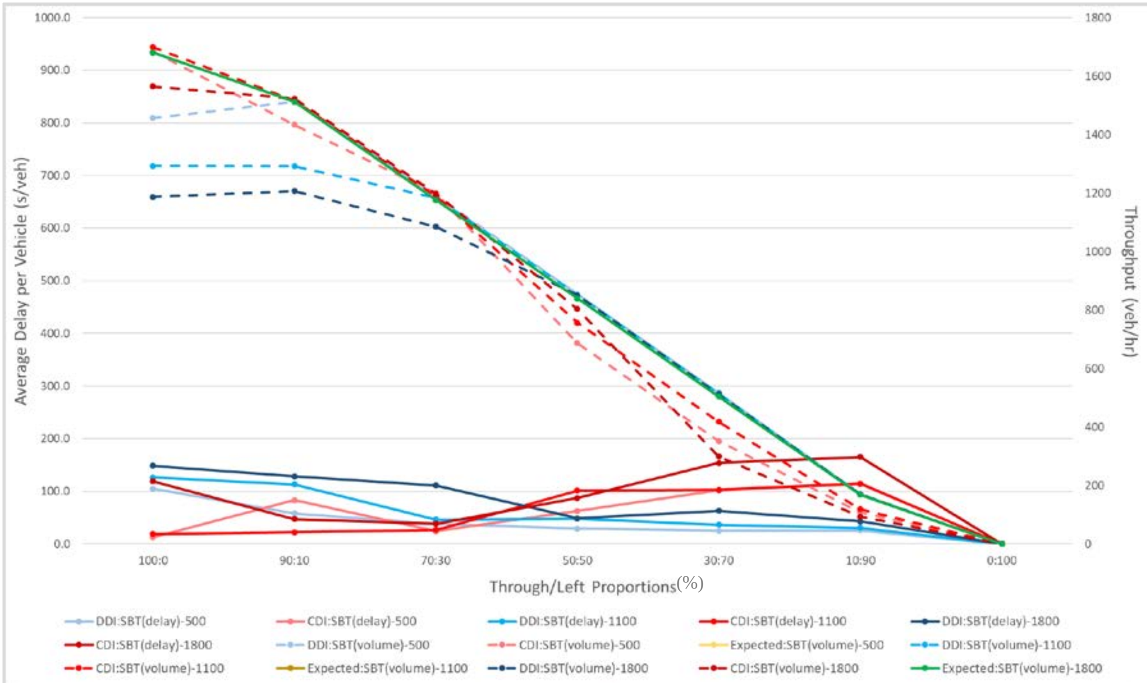


Figure E-10: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

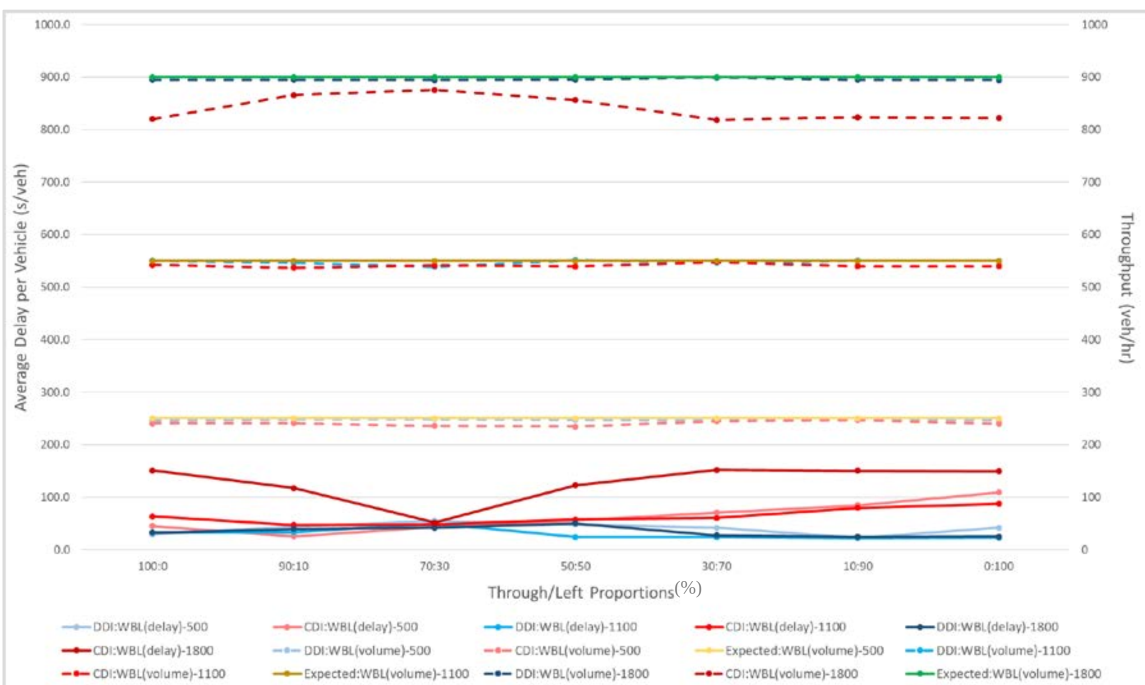


Figure E-11: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

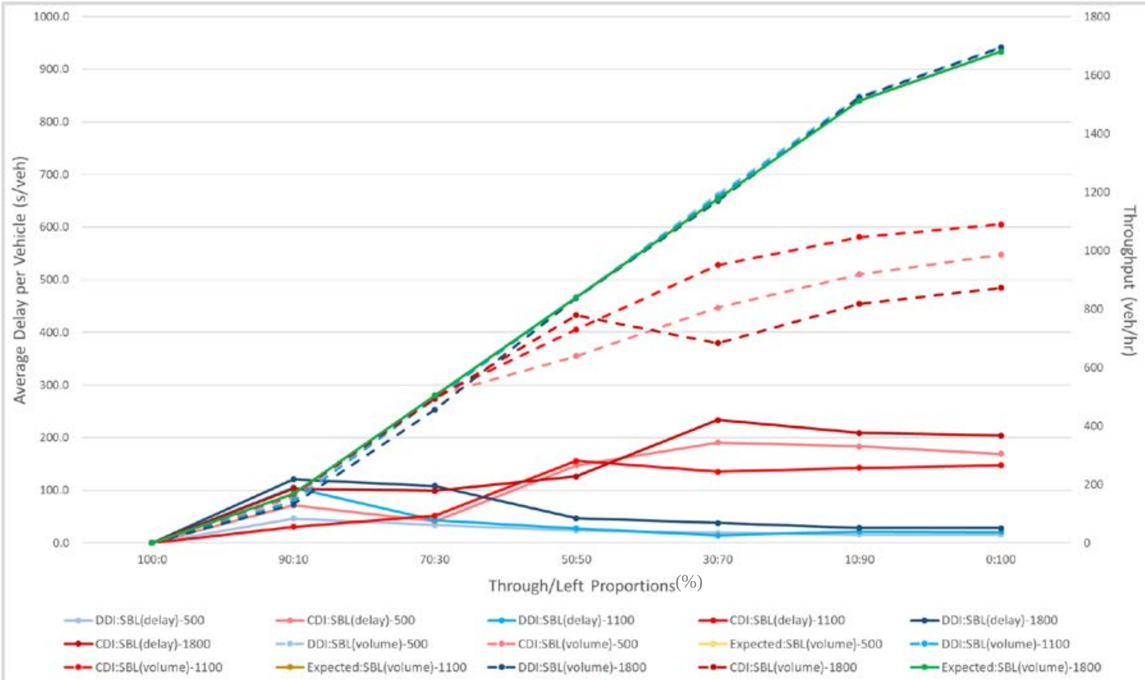


Figure E-12: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC1

E.1.3 Cross street Demand: 2500 vph

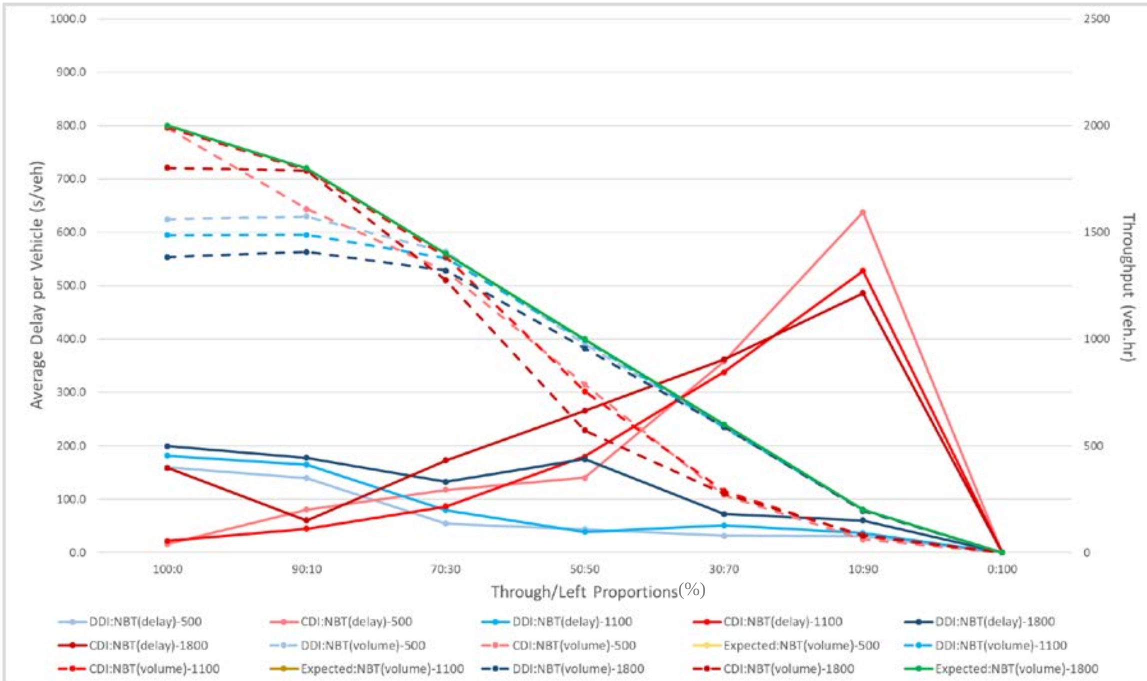


Figure E-13: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

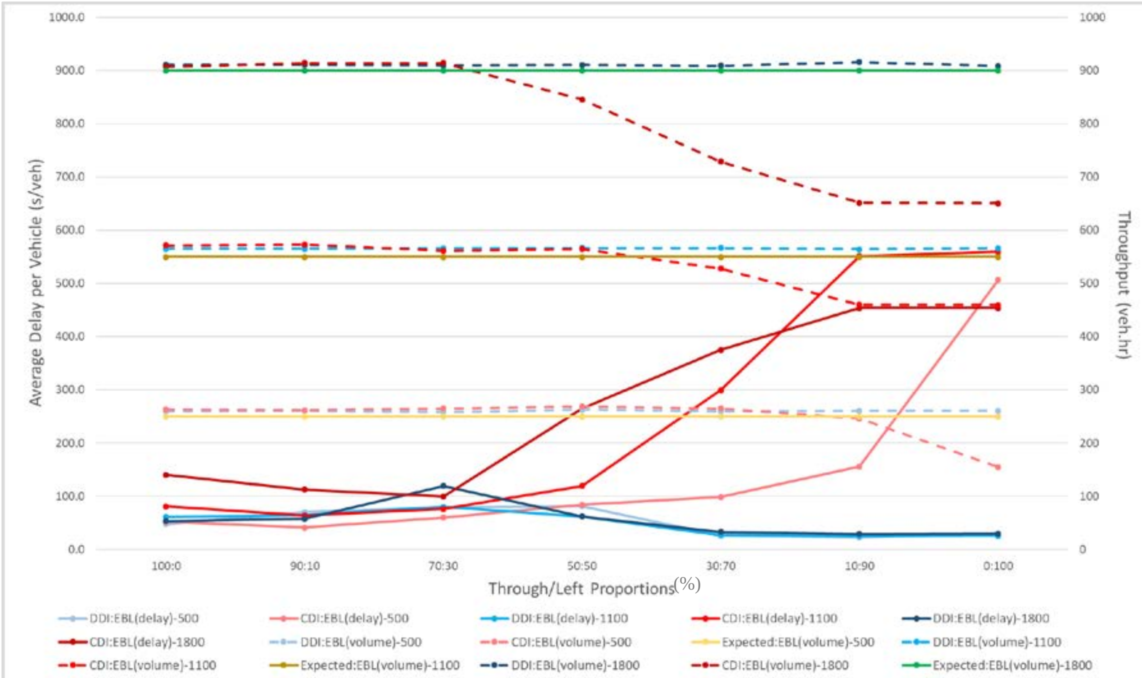


Figure E-14: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

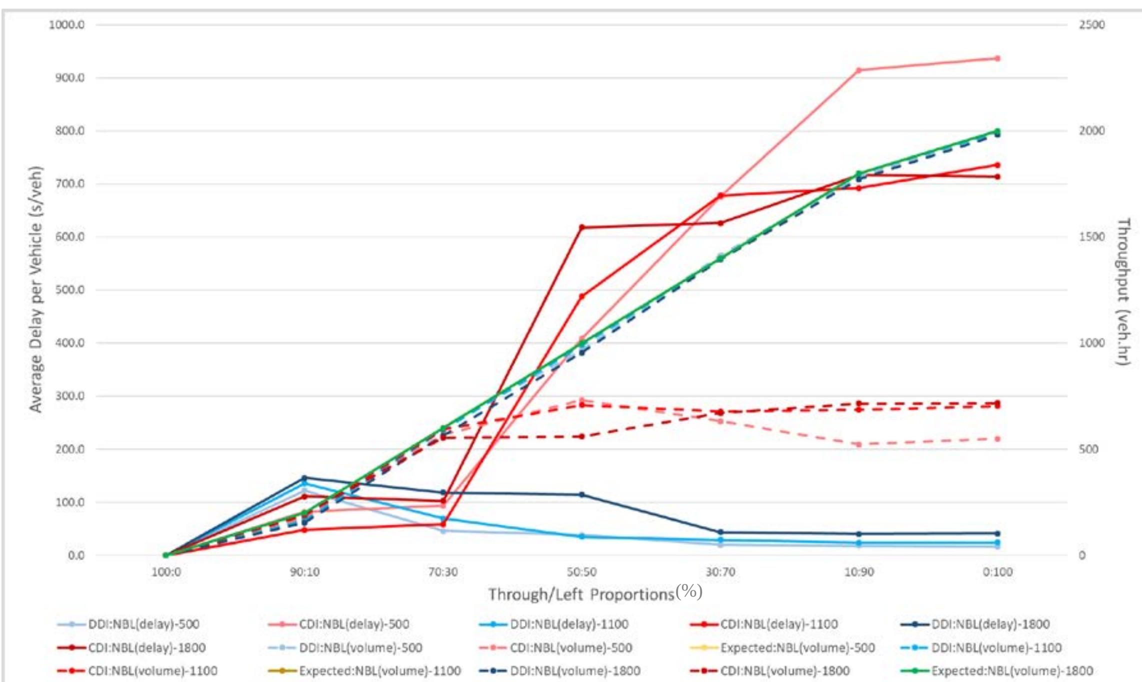


Figure E-15: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

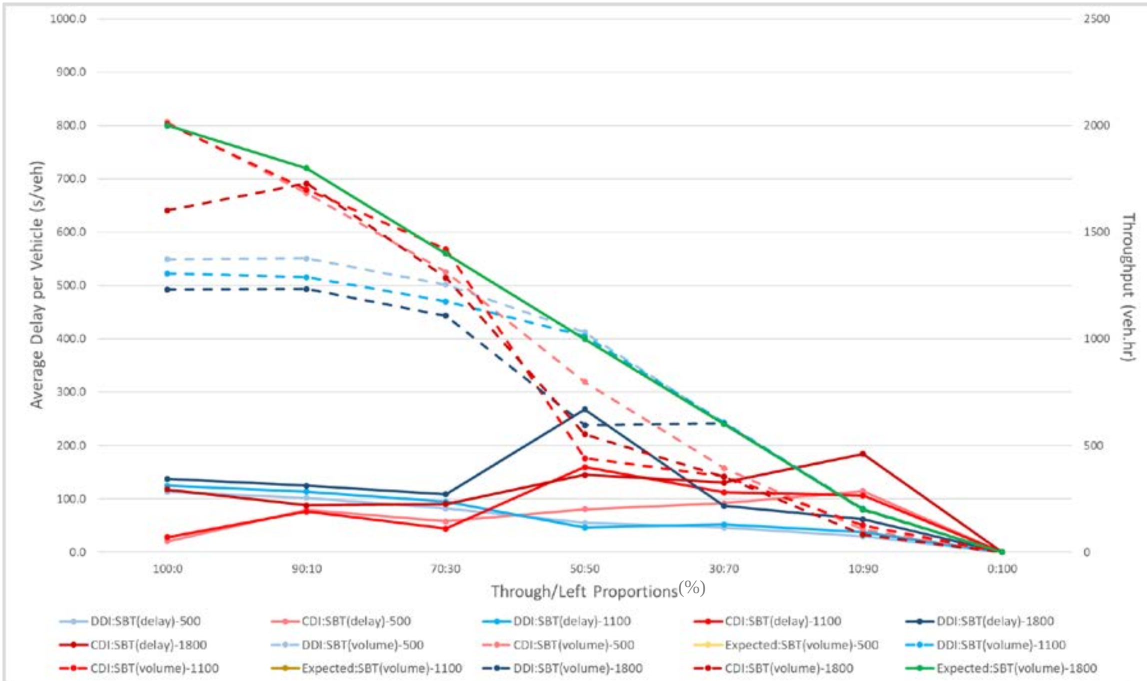


Figure E-16: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

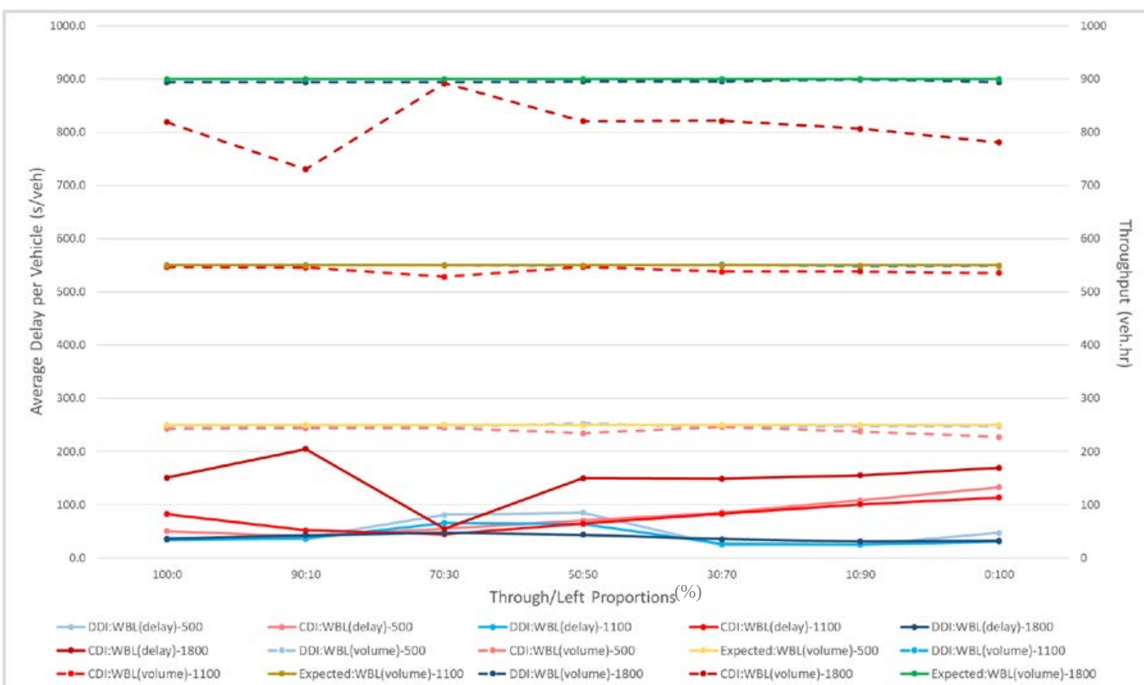


Figure E-17: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

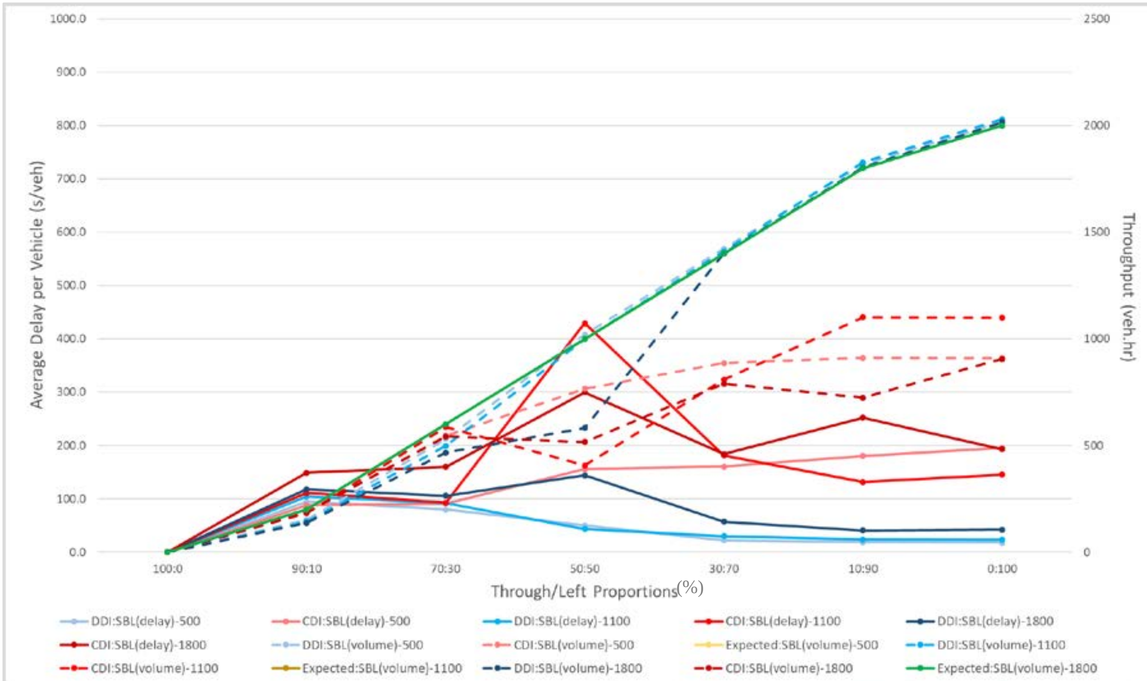


Figure E-18: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC1

E.2 Lane Configuration 2

E.2.1 Cross street Demand: 1500 vph

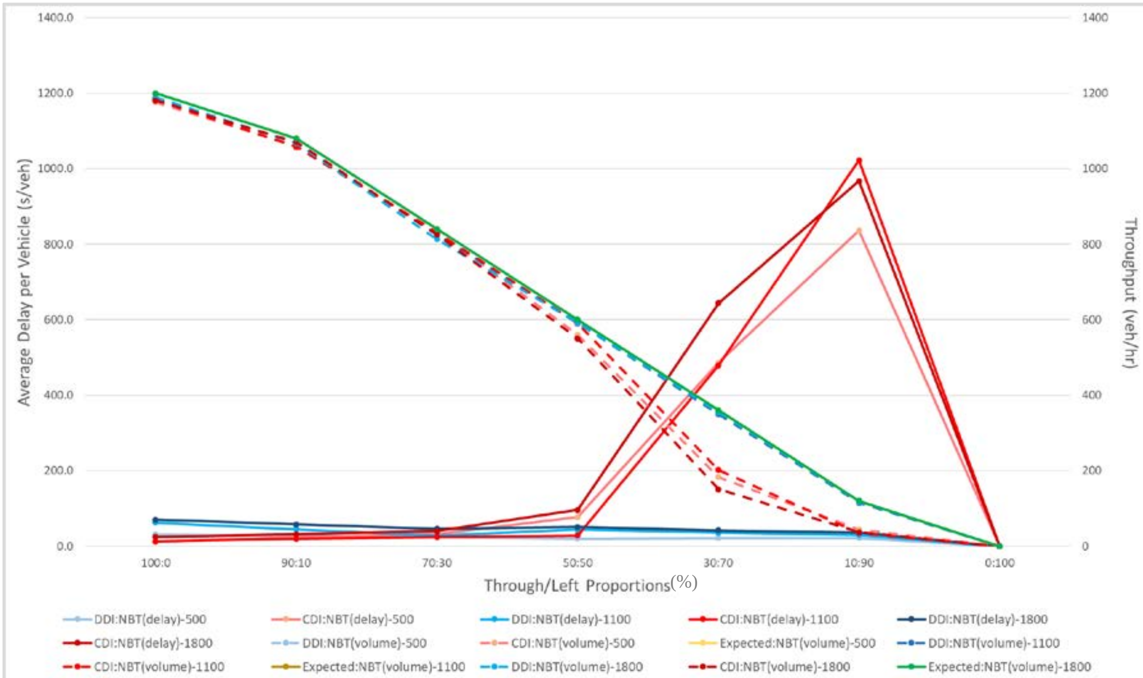


Figure E-19: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

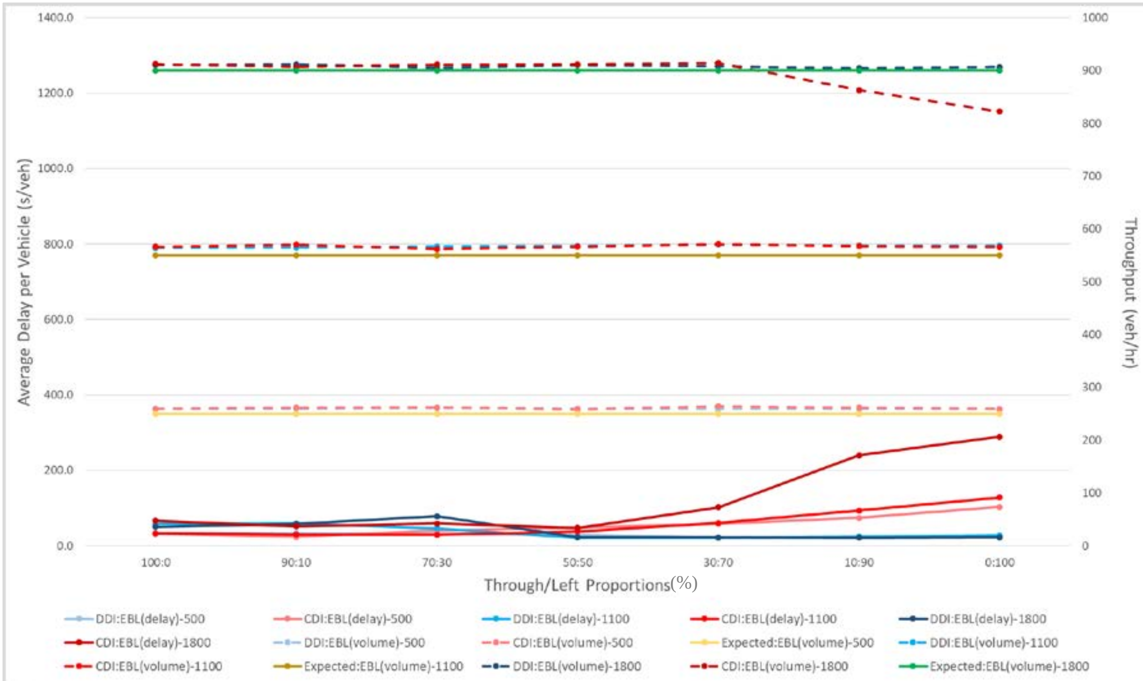


Figure E-20: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

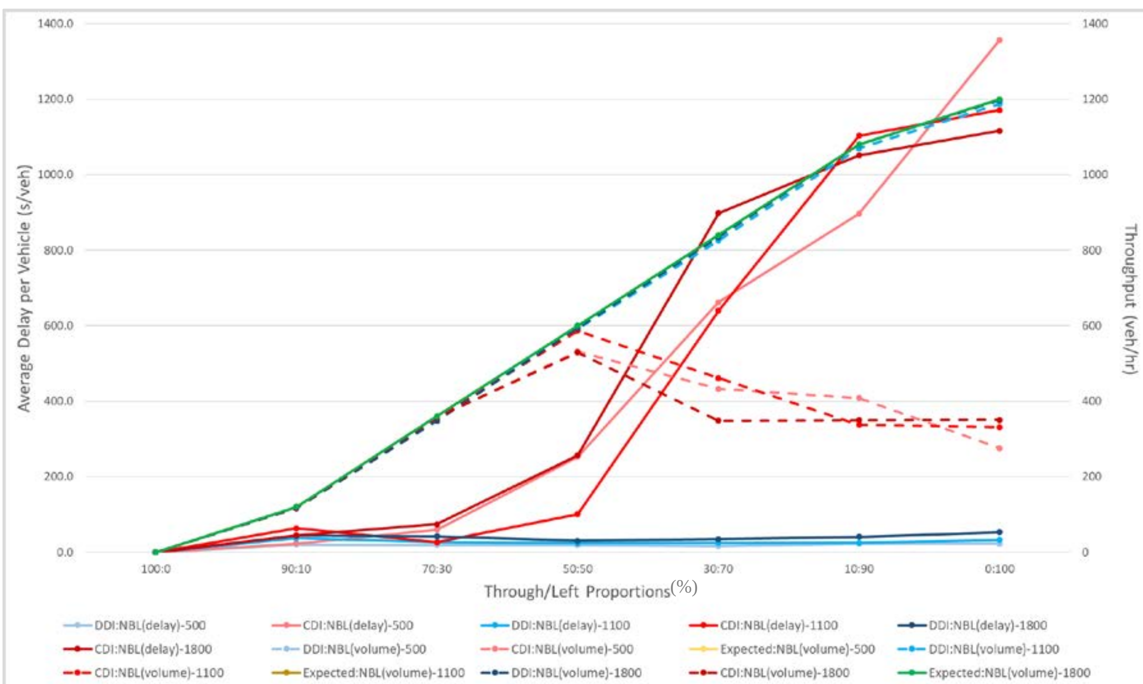


Figure E-21: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

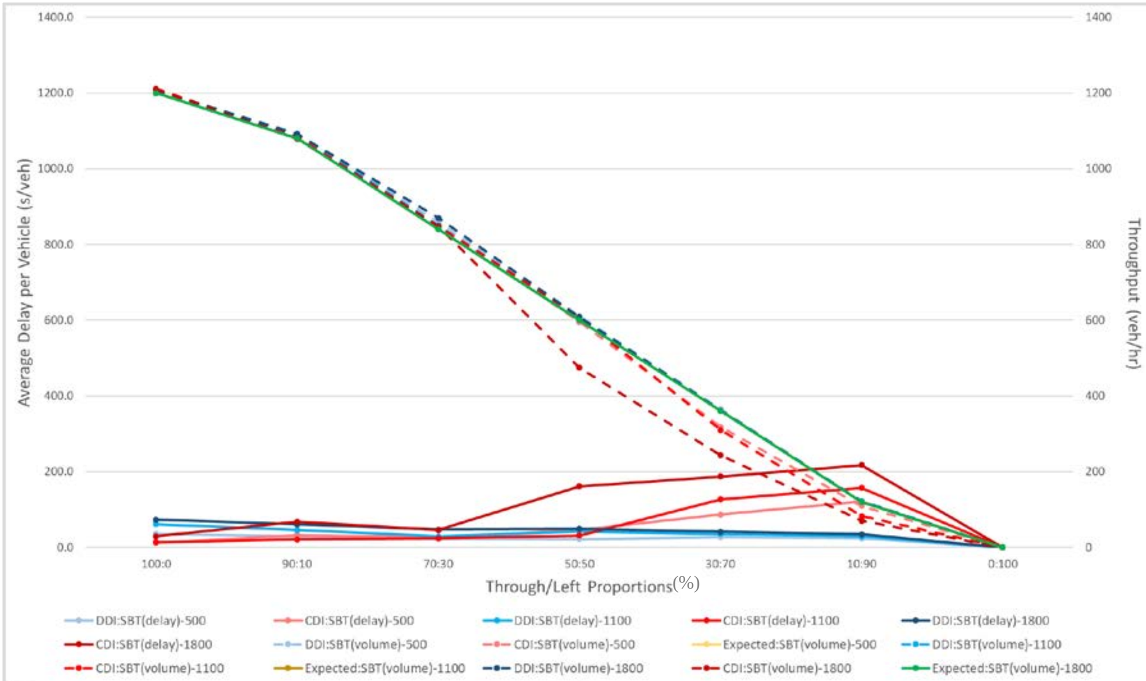


Figure E-22: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

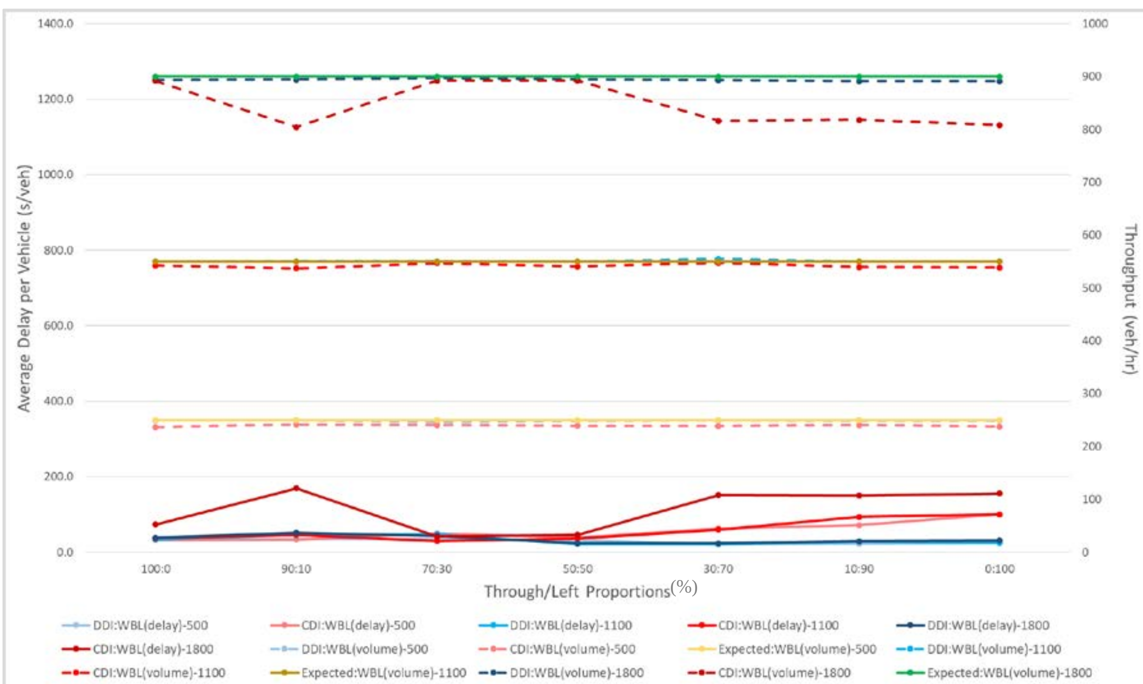


Figure E-23: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

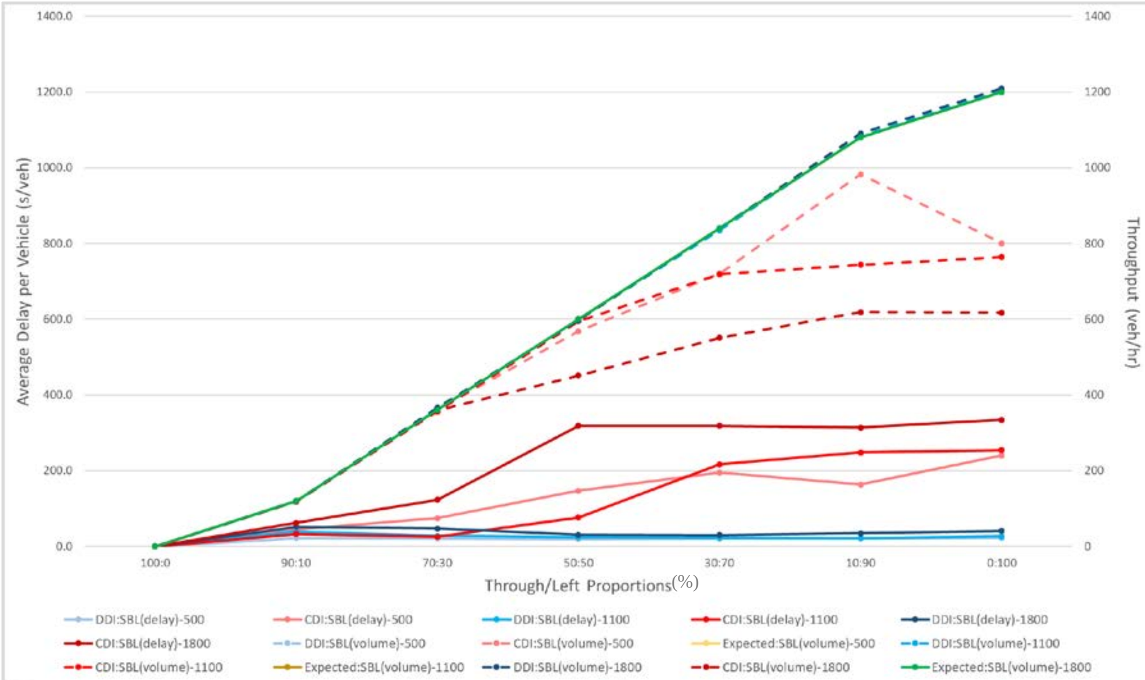


Figure E-24: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC2

E.2.2 Cross street Demand: 2100 vph

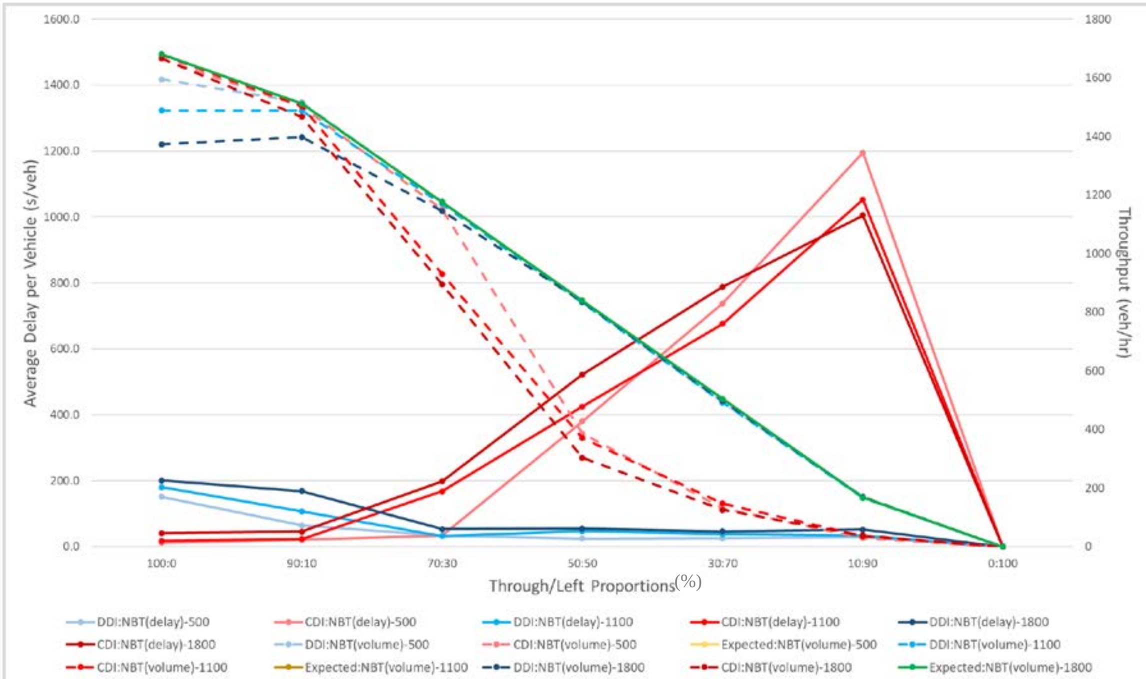


Figure E-25: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

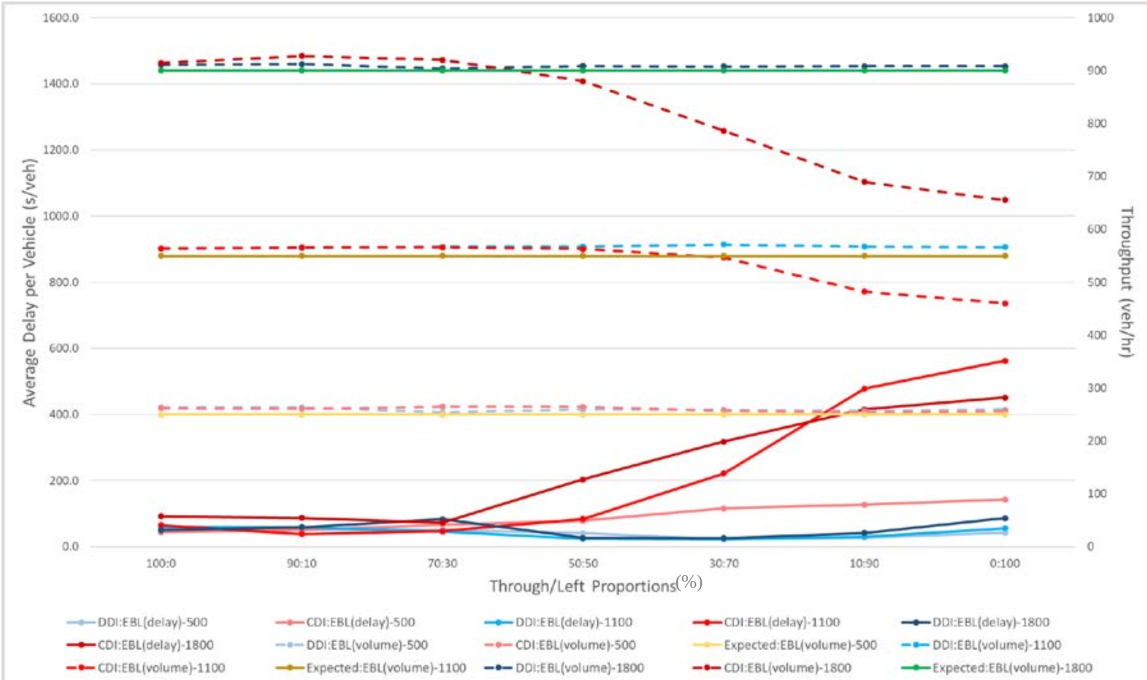


Figure E-26: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

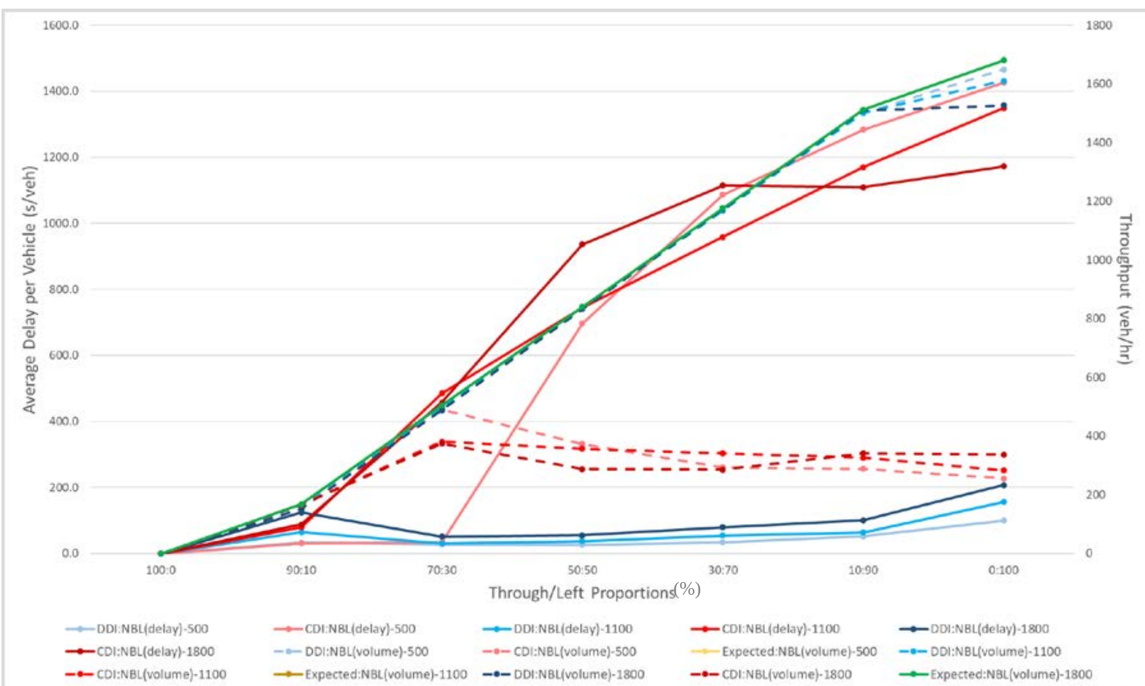


Figure E-27: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

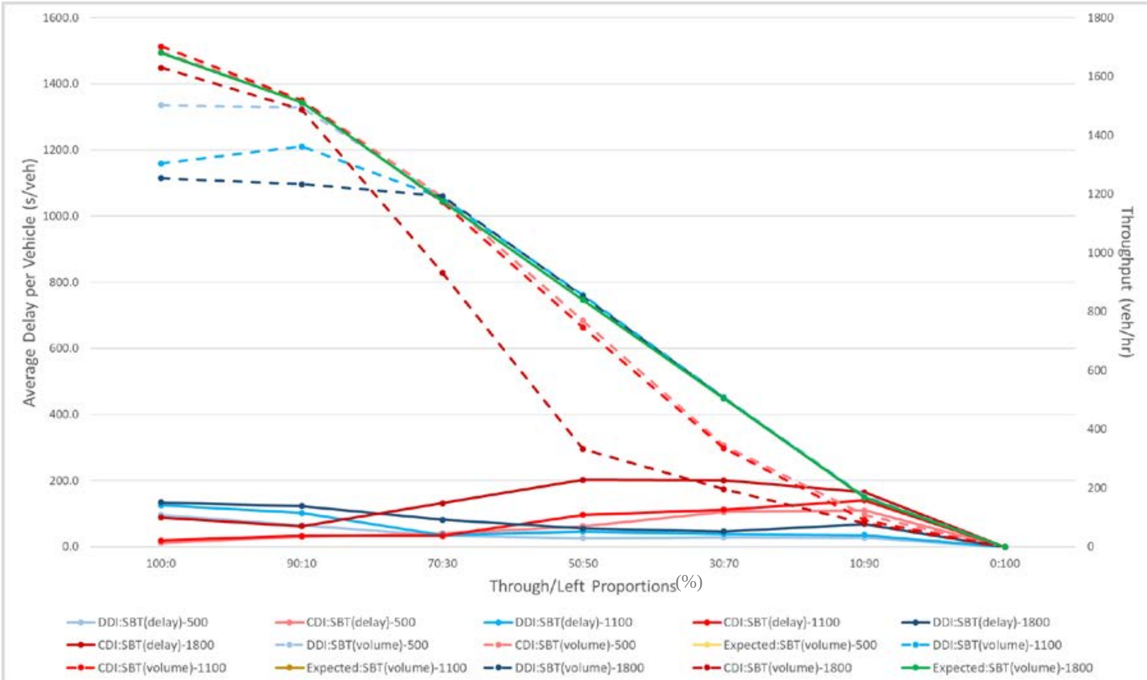


Figure E-28: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

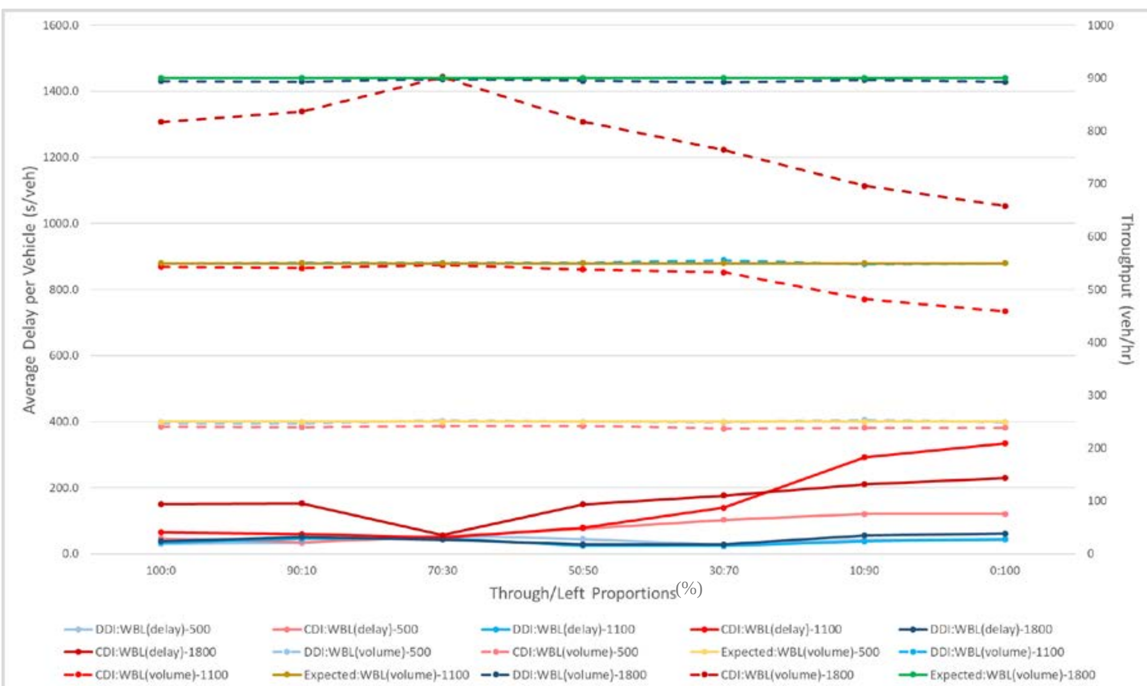


Figure E-29: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

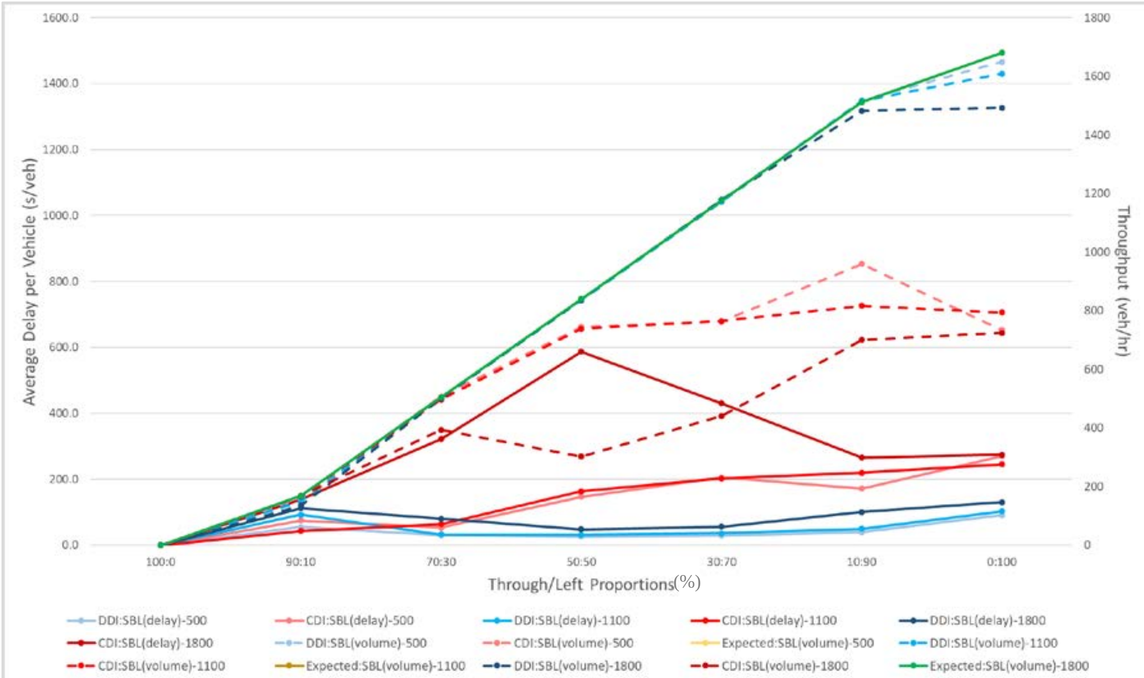


Figure E-30: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC2

E.2.3 Cross street Demand: 2500 vph

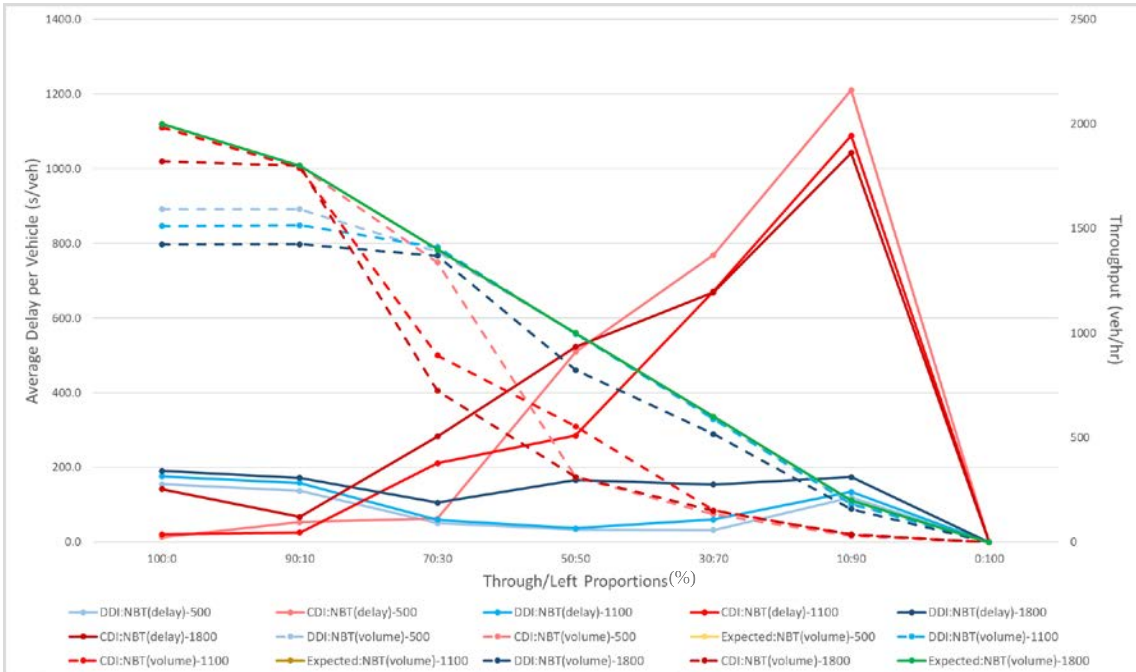


Figure E-31: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

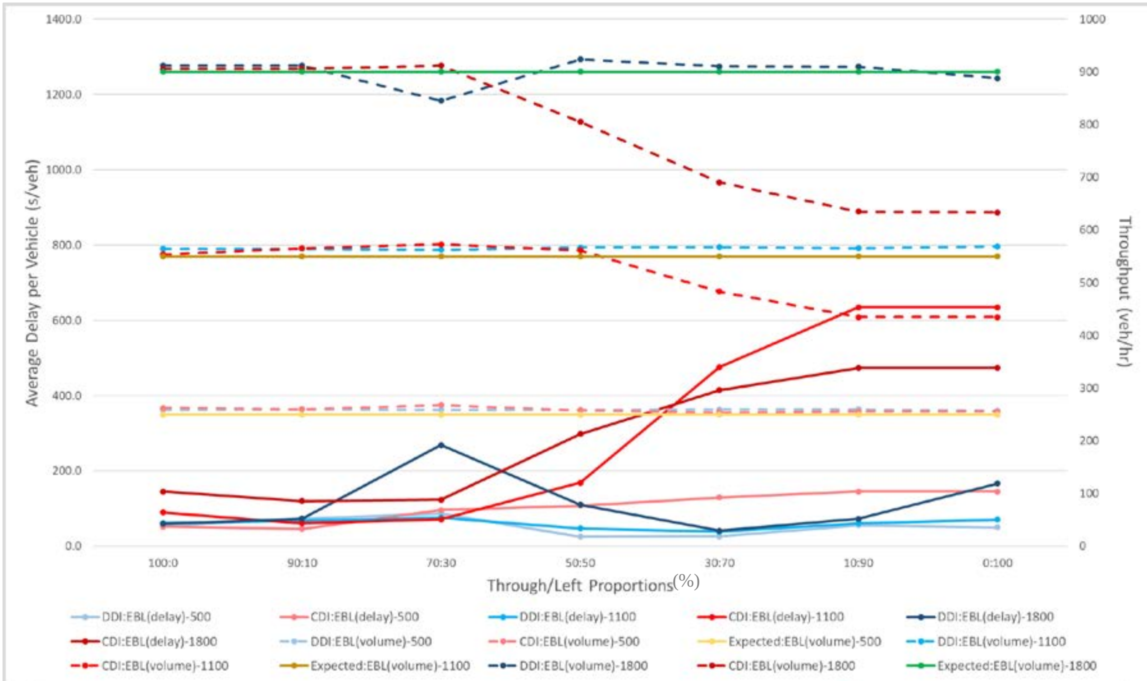


Figure E-32: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

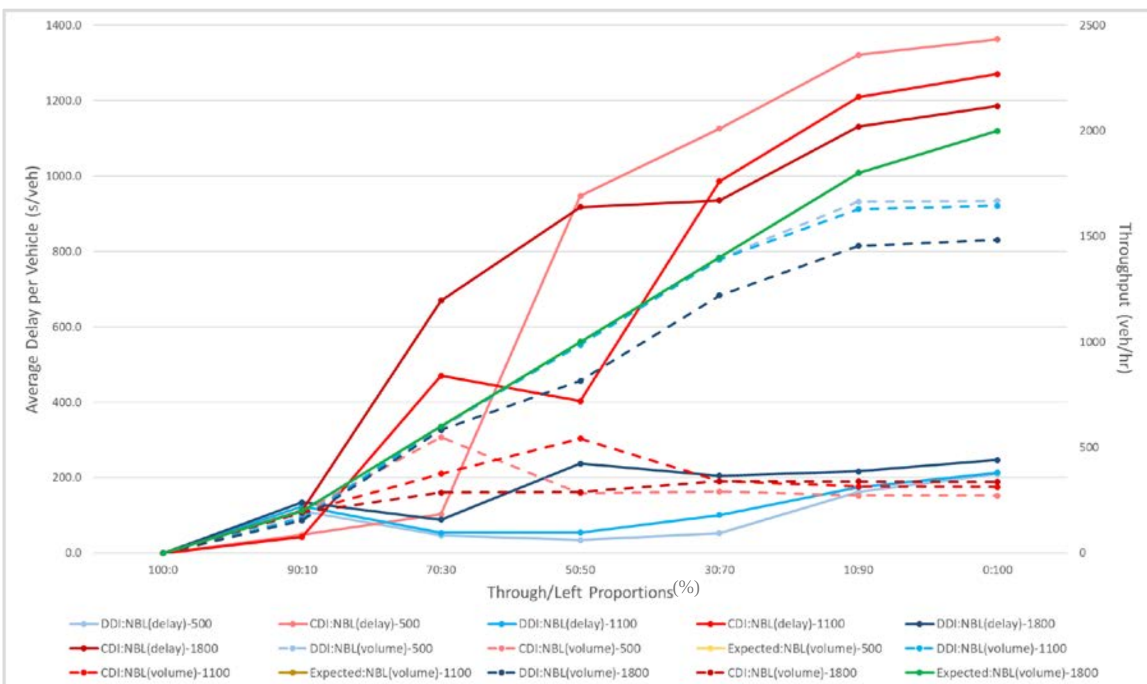


Figure E-33: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

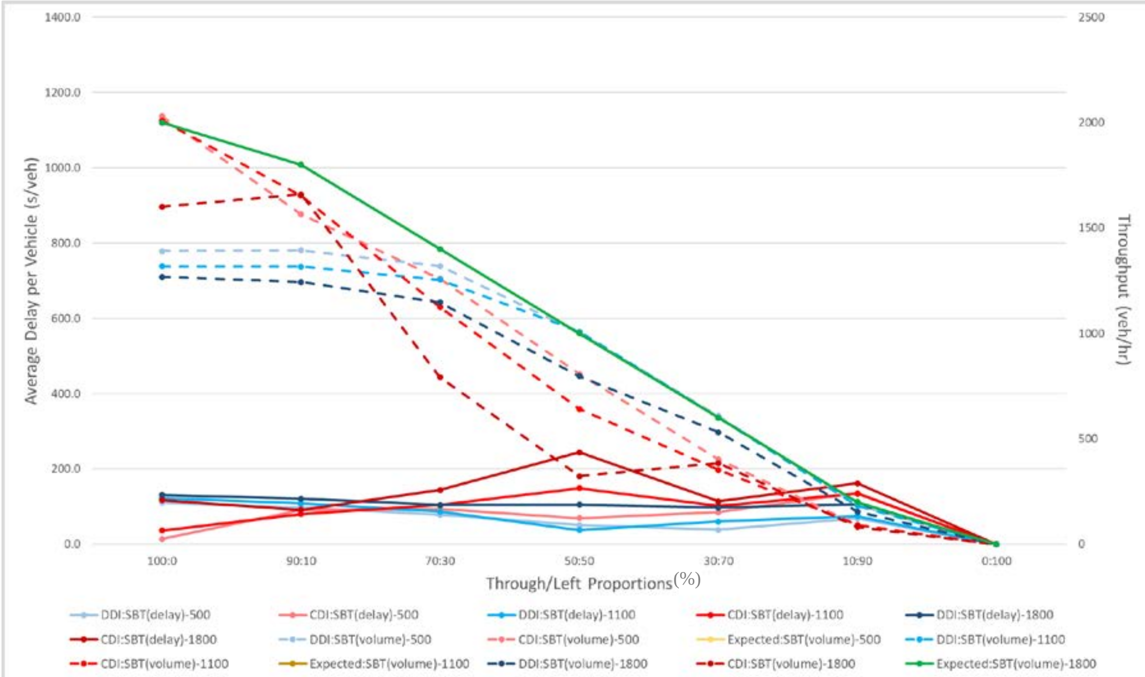


Figure E-34: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

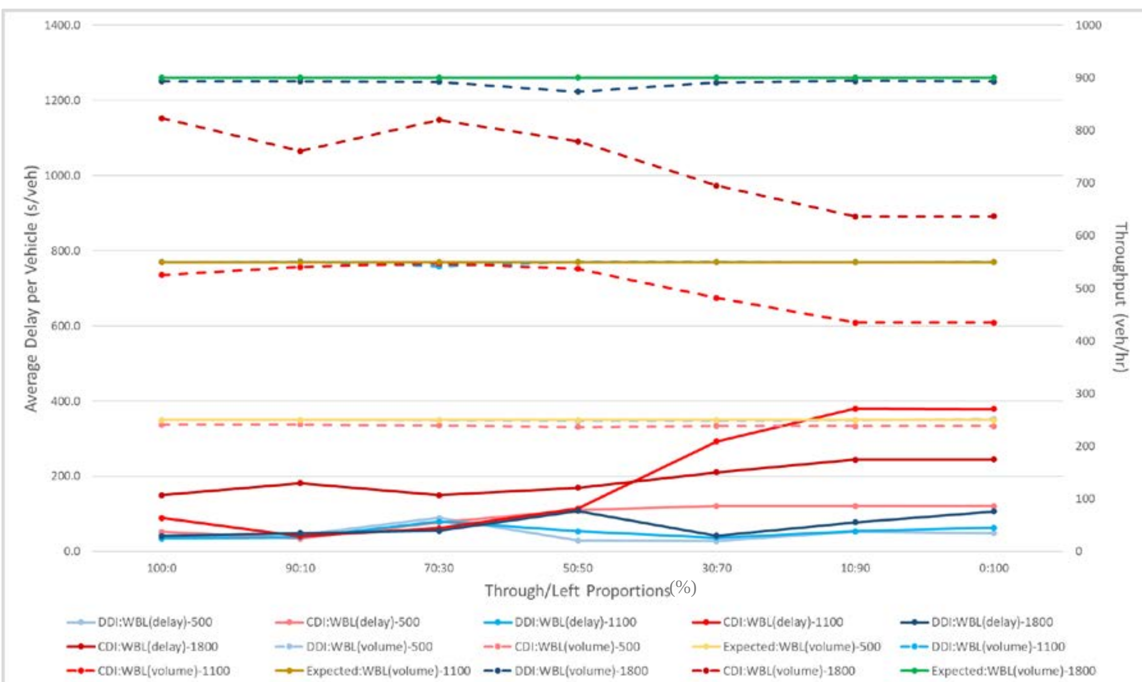


Figure E-35: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

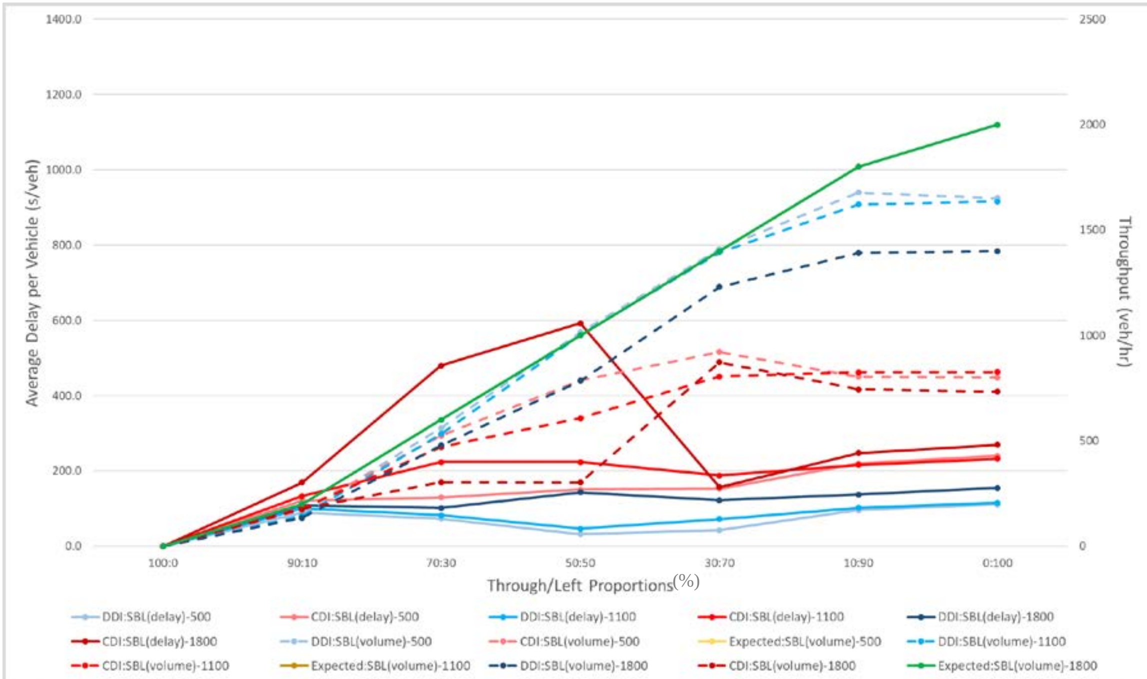


Figure E-36: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC2

E.3 Lane Configuration 3

E.3.1 Cross street Demand: 1500 vph

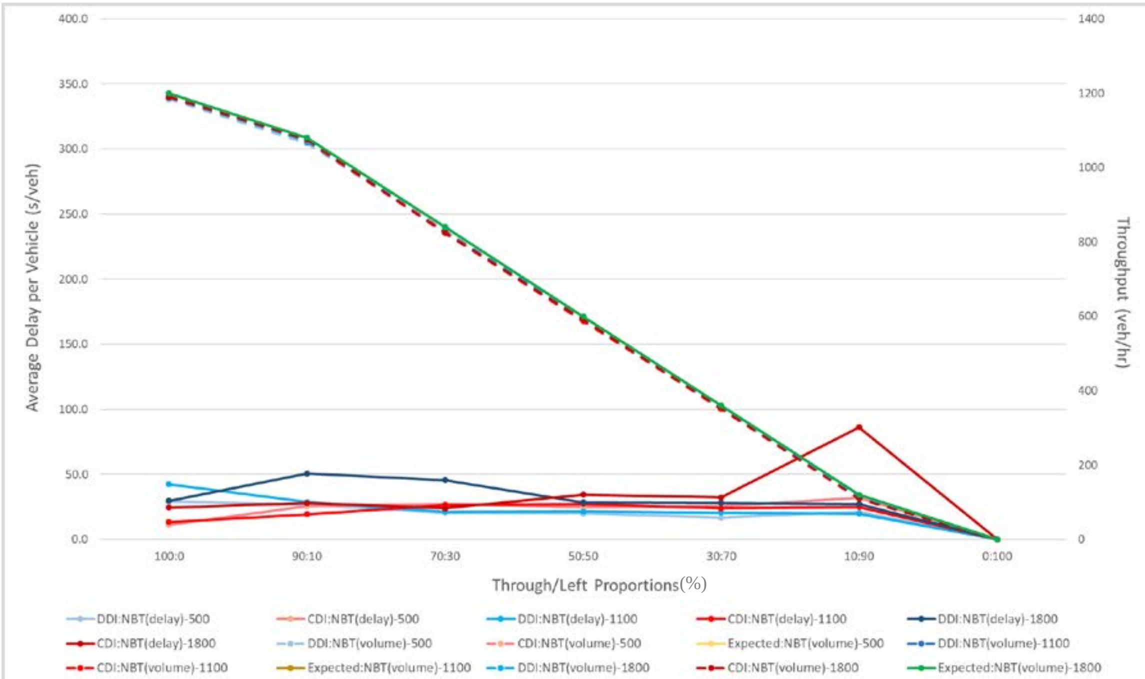


Figure E-37: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

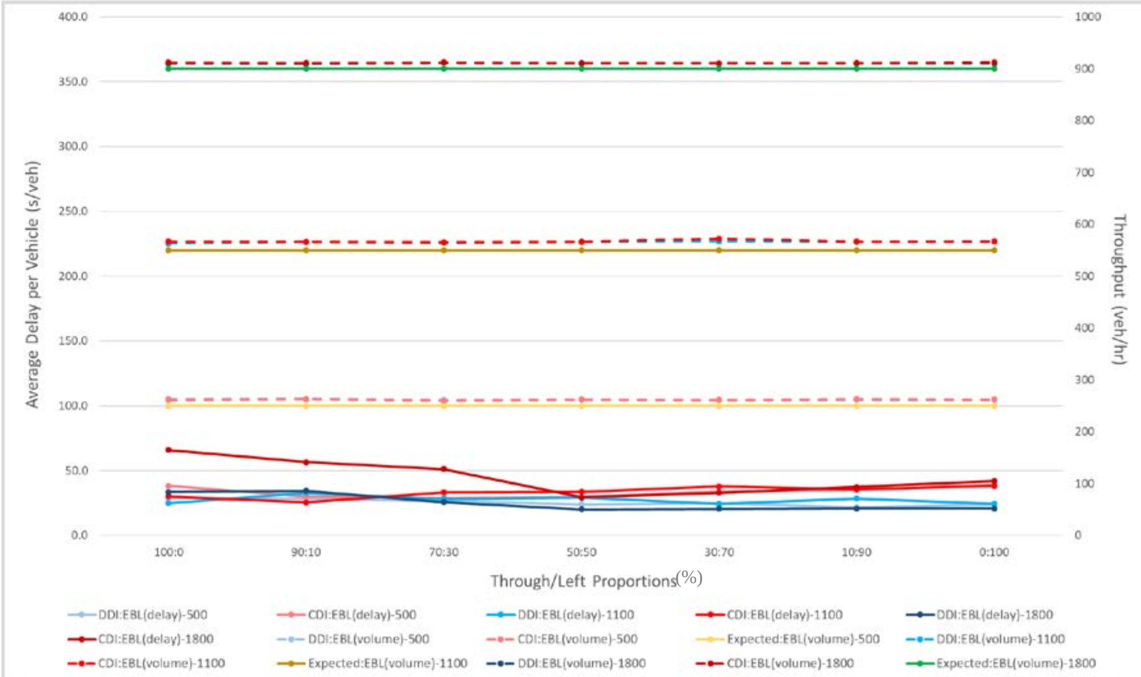


Figure E-38: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

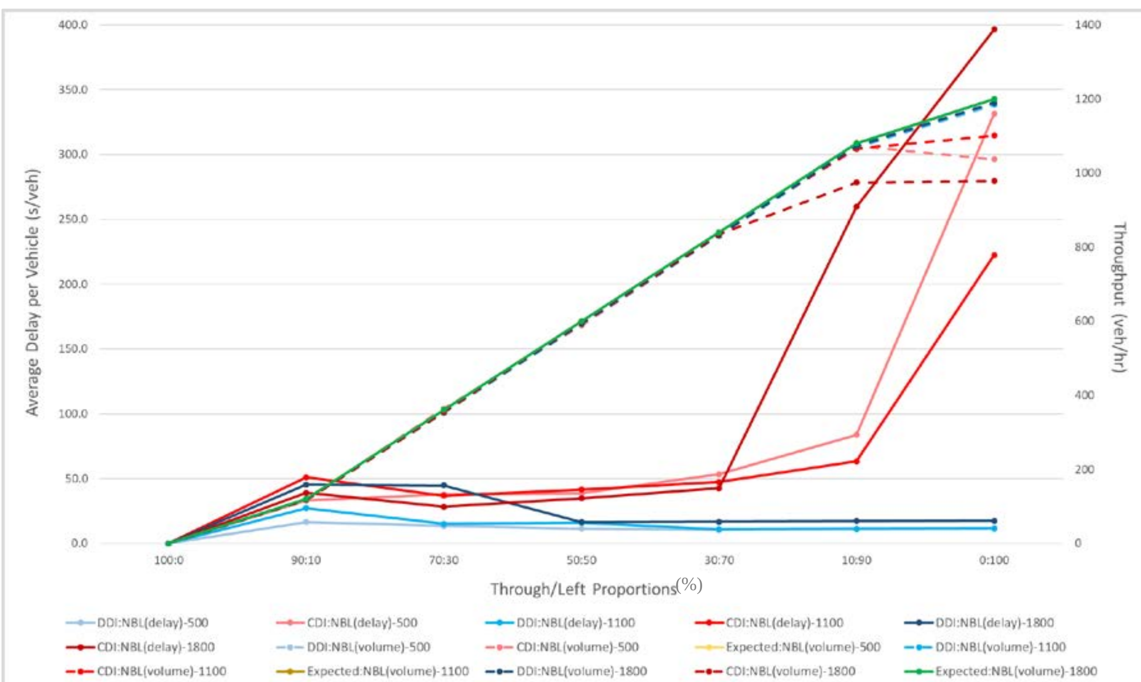


Figure E-39: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

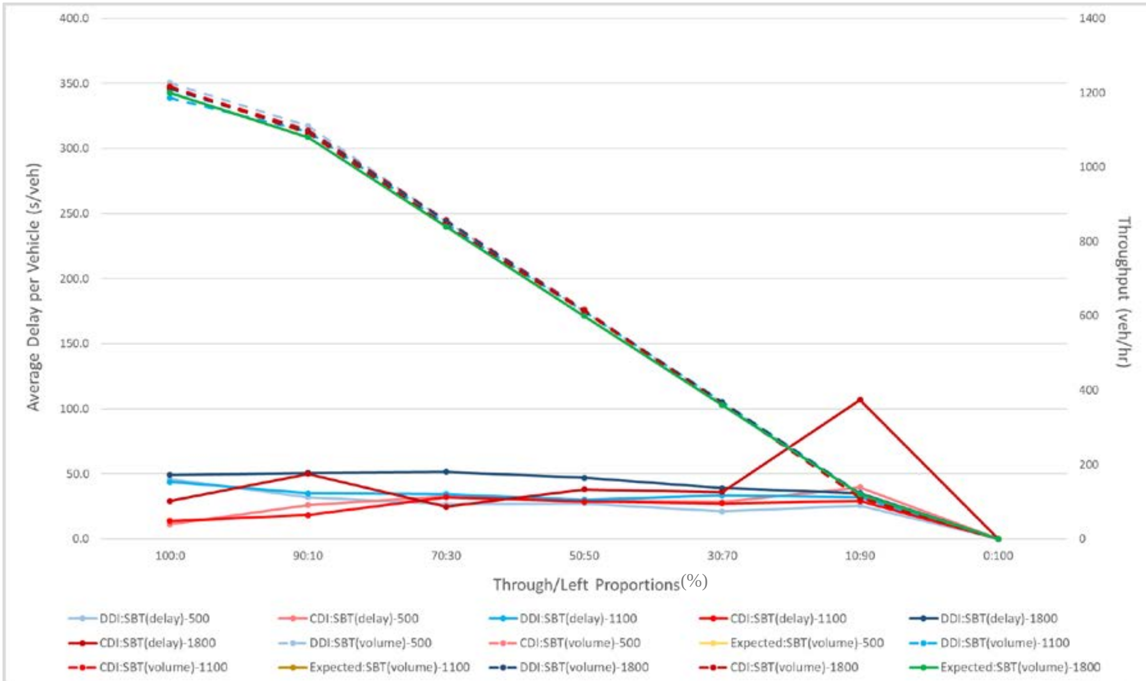


Figure E-40: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

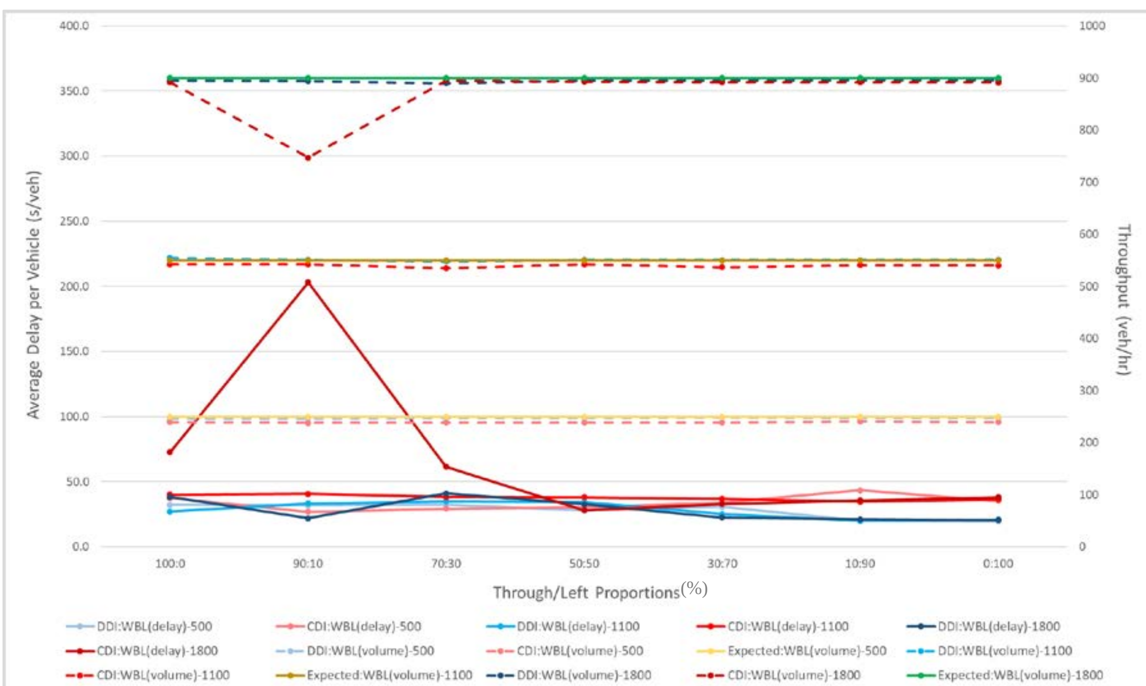


Figure E-41: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

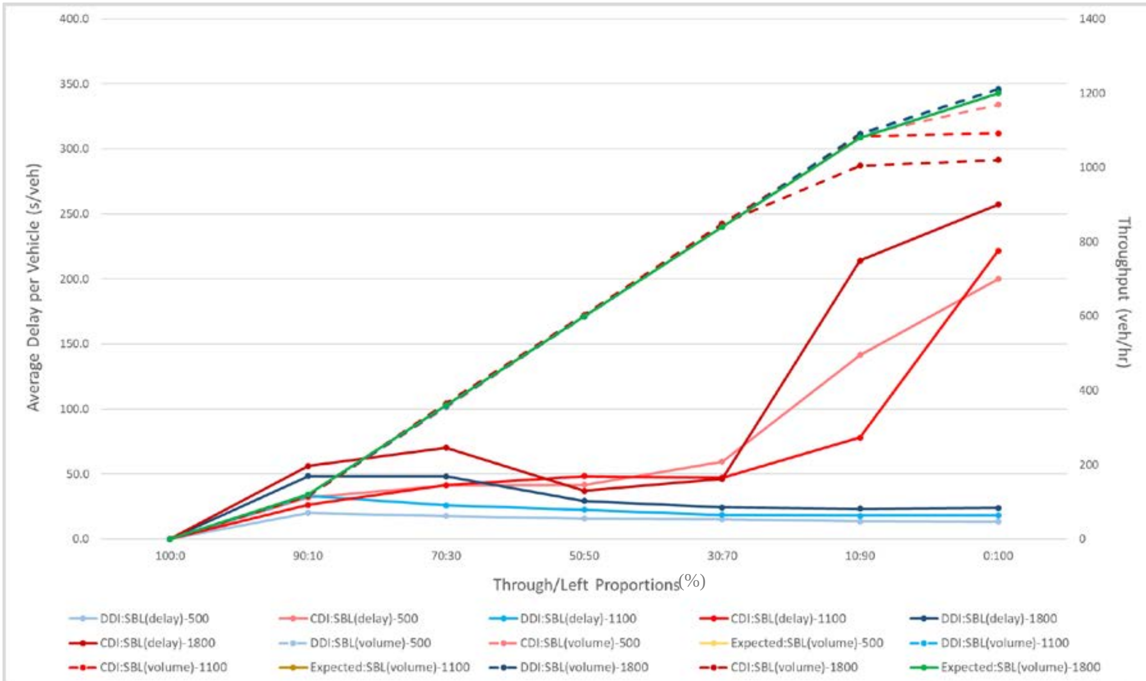


Figure E-42: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 1500 vph at different off-ramp demands and through/left proportions for LC3

E.3.2 Cross street Demand: 2100 vph

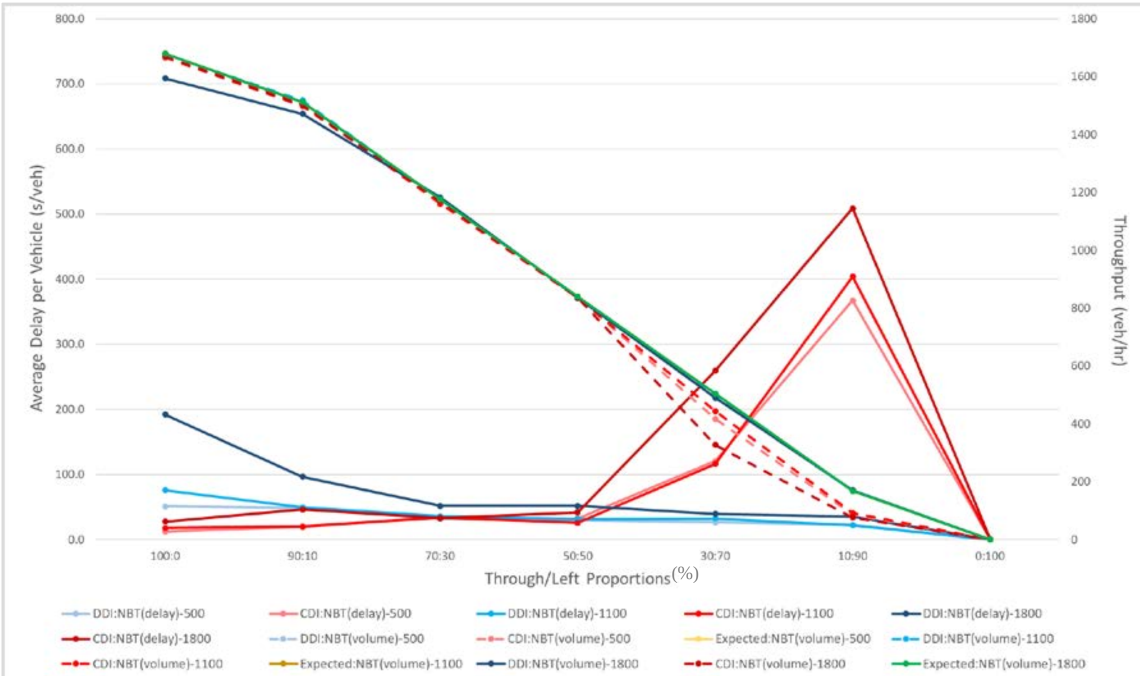


Figure E-43: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

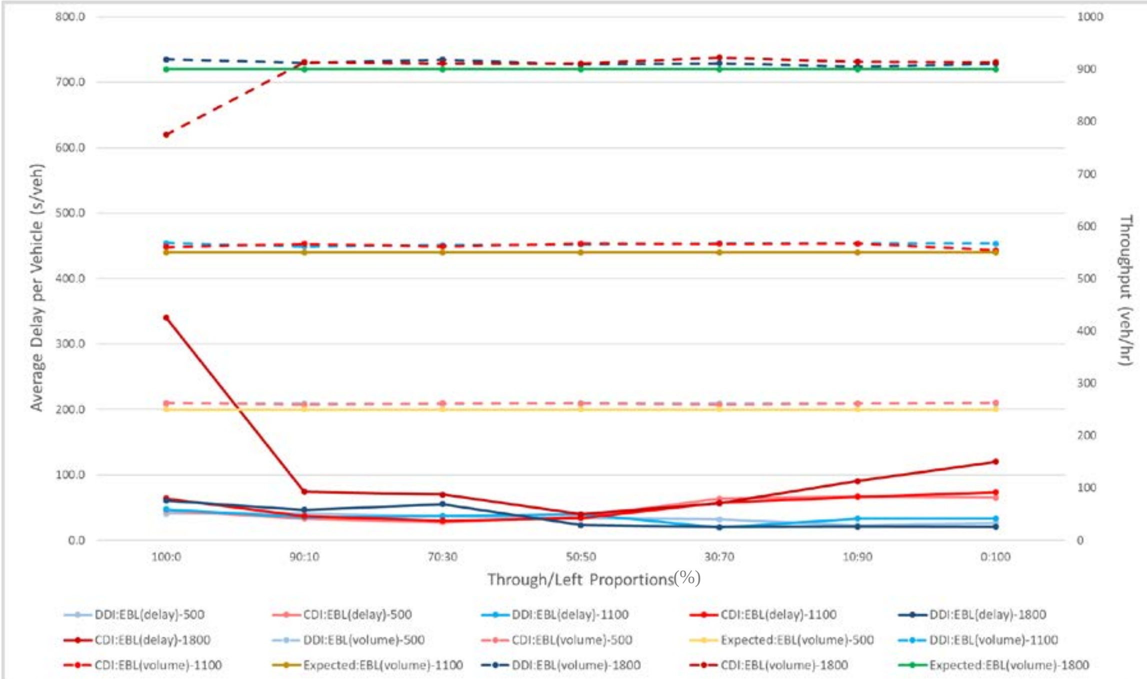


Figure E-44: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

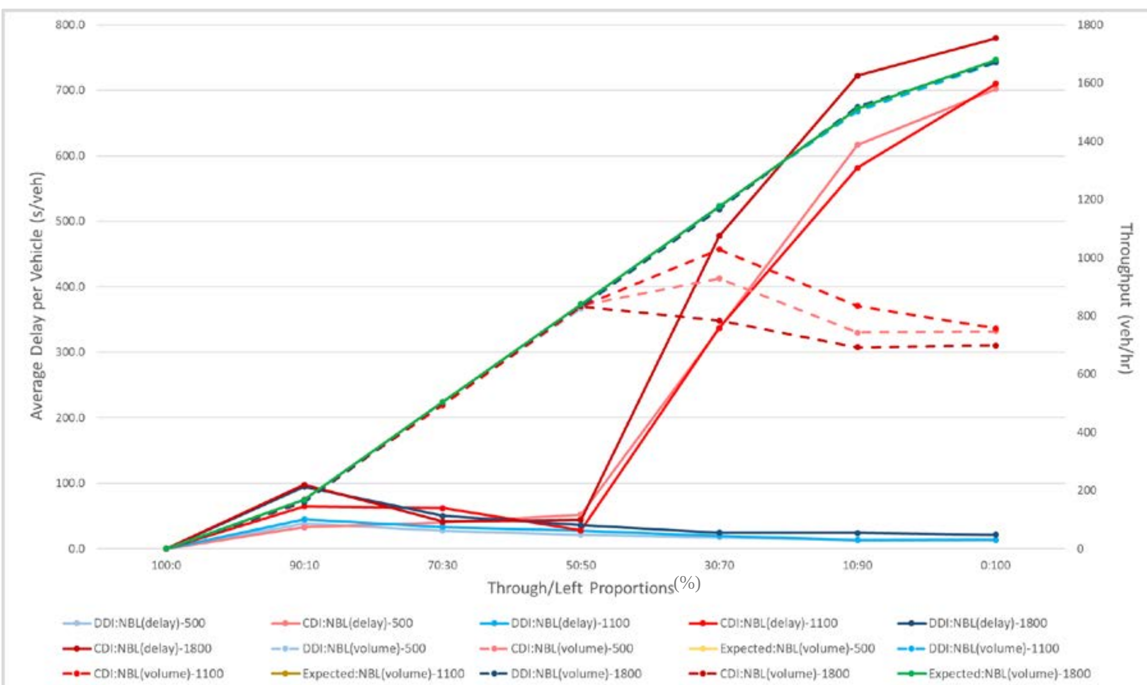


Figure E-45: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

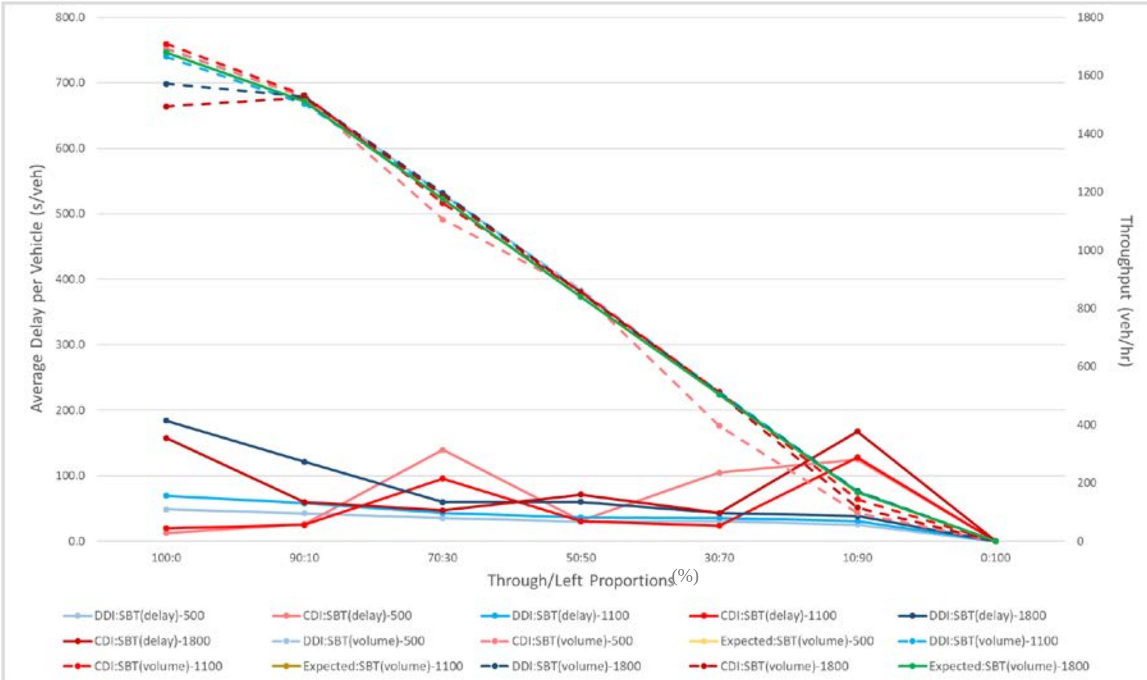


Figure E-46: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

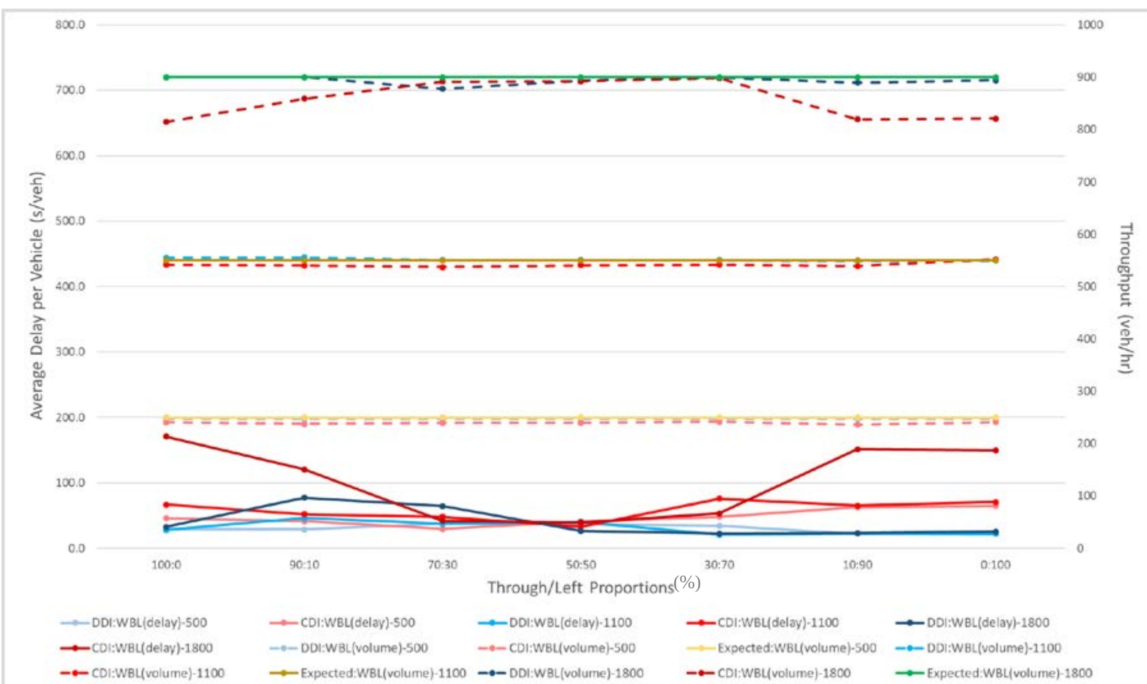


Figure E-47: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

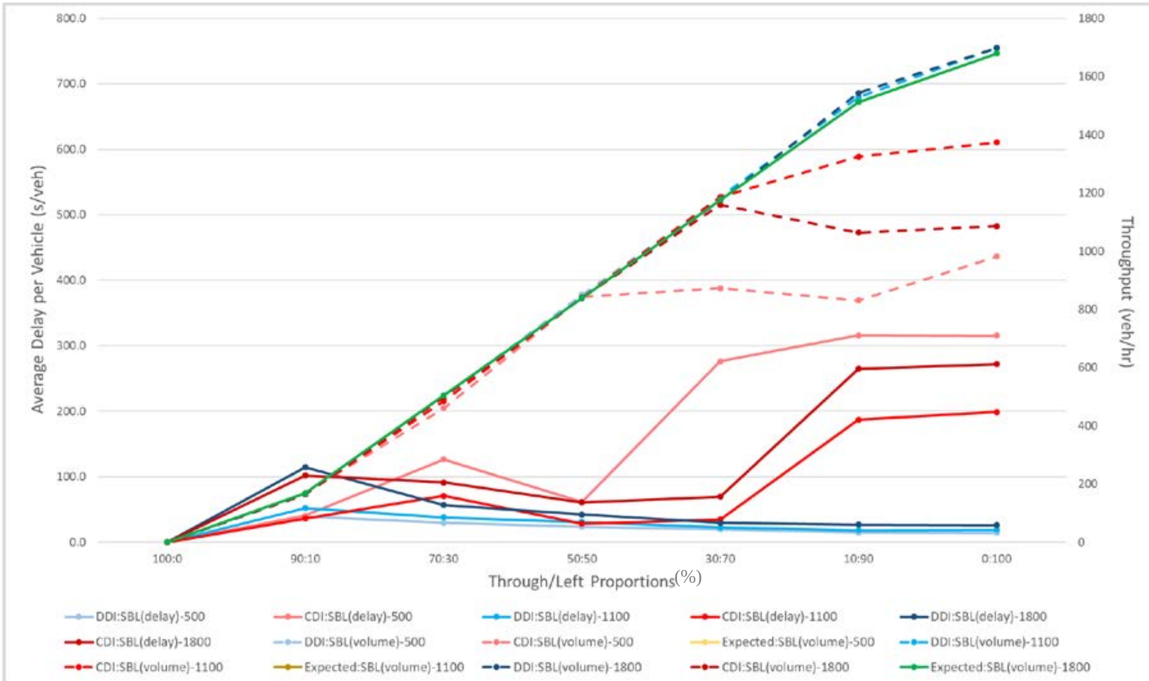


Figure E-48: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2100 vph at different off-ramp demands and through/left proportions for LC3

E.3.3 Cross street Demand: 2500 vph

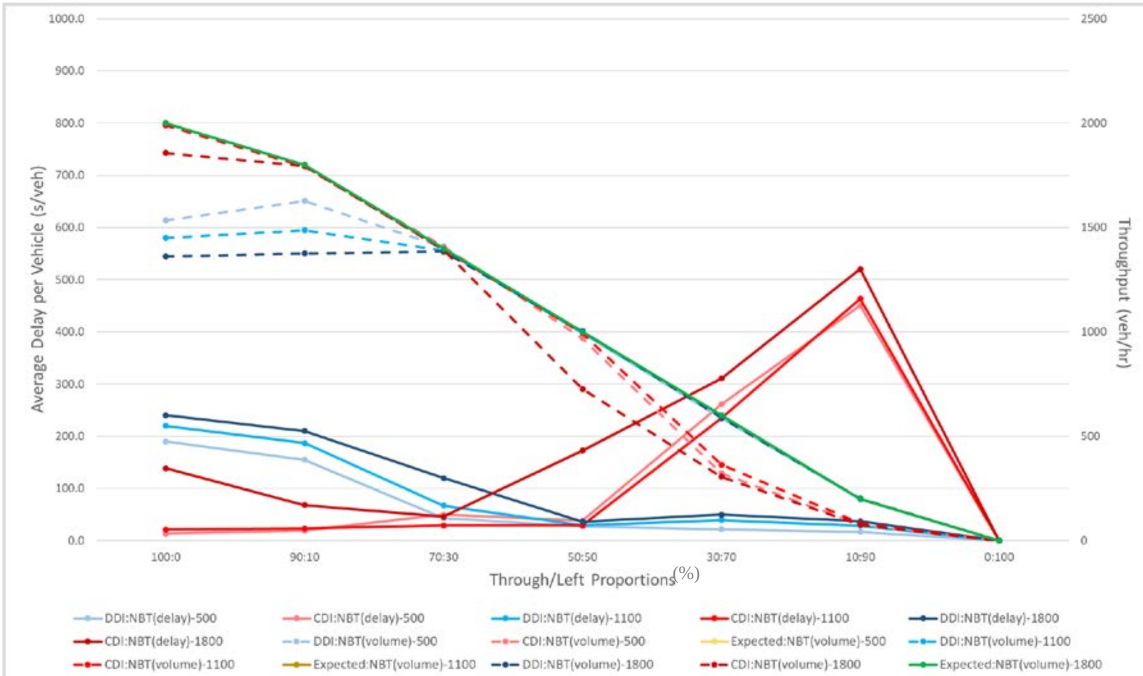


Figure E-49: DDI and CDI average delay per vehicle and throughput on NBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

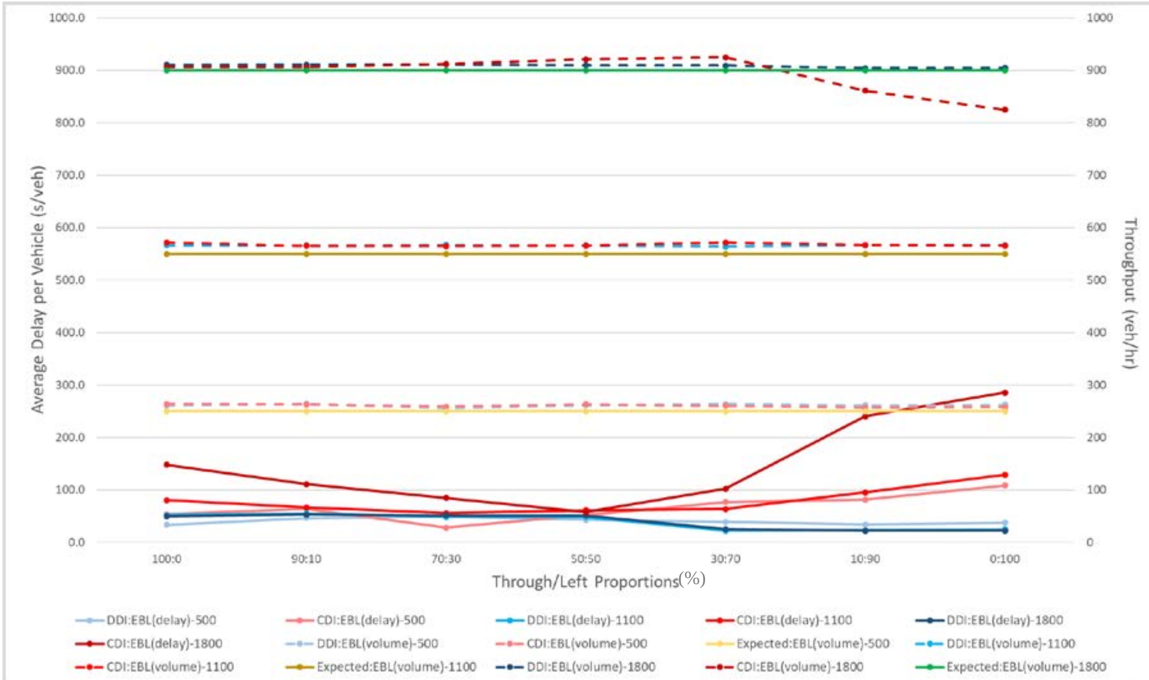


Figure E-50: DDI and CDI average delay per vehicle and throughput on EBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

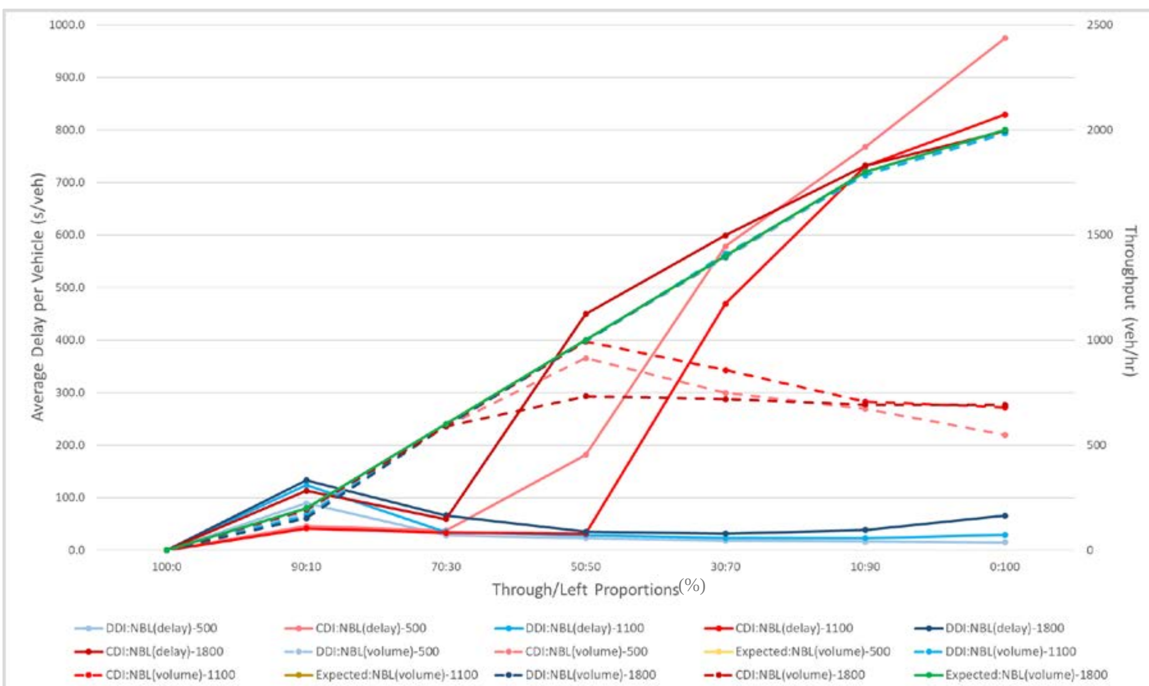


Figure E-51: DDI and CDI average delay per vehicle and throughput on NBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

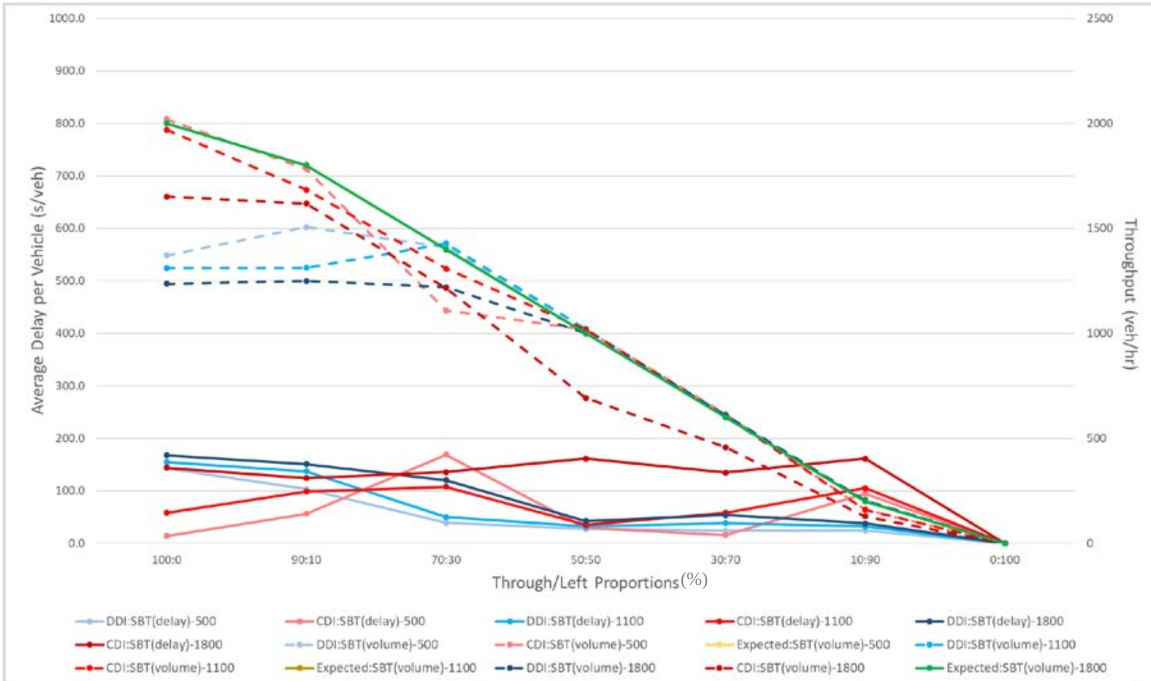


Figure E-52: DDI and CDI average delay per vehicle and throughput on SBT with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

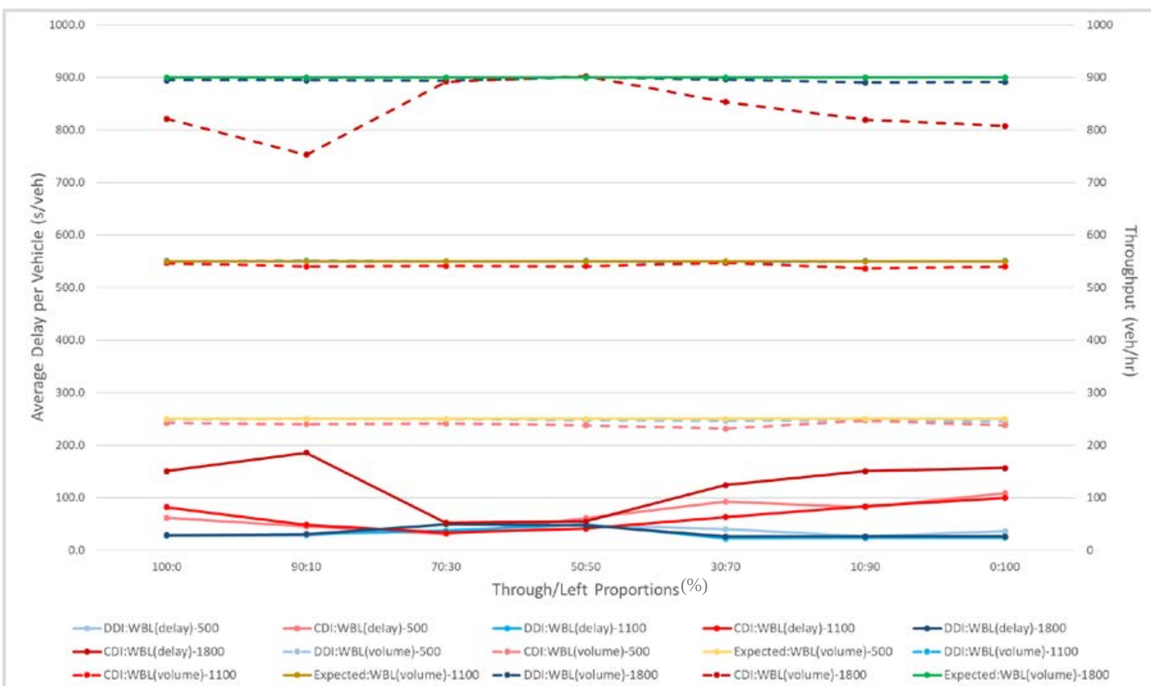


Figure E-53: DDI and CDI average delay per vehicle and throughput on WBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

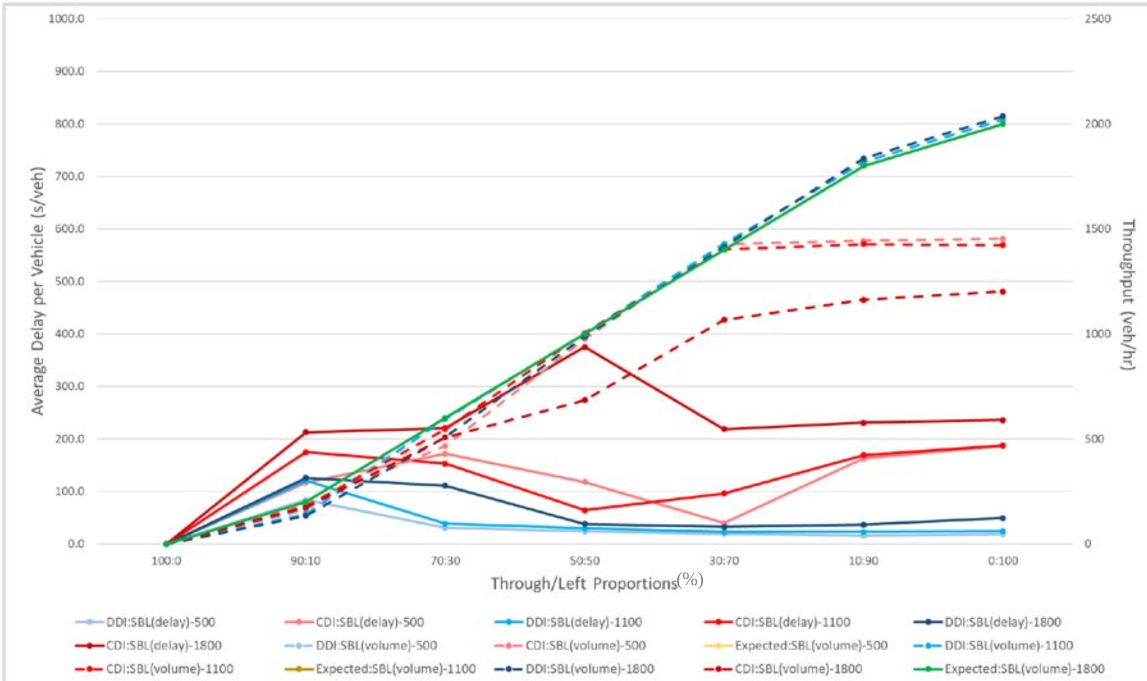


Figure E-54: DDI and CDI average delay per vehicle and throughput on SBL with cross street demand of 2500 vph at different off-ramp demands and through/left proportions for LC3

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